Social and Emotional Learning: Research, Practice, and Policy 6 (2025) 100167

Contents lists available at ScienceDirect

Social and Emotional Learning: Research, Practice, and Policy

journal homepage: www.journals.elsevier.com/social-and-emotional-learning-research-practice-and-policy

Developing children's innate systems intelligence to enhance social and emotional learning

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ARTICLE INFO

Keywords:
Systems intelligence
Social and emotional learning
Educational innovation
Learner-centered pedagogy
Project based learning

ABSTRACT

This paper explores the concept of *systems intelligence* in children and highlights its links to social and emotional learning (SEL), proposing that young people possess an innate capacity to understand interdependence, relationships, and change within complex systems. The argument centers on the importance and feasibility of cultivating systems intelligence in children and youth as a response to the complex challenges societies face today. Traditional education often overlooks this innate capacity, emphasizing technical academic content and reductionistic approaches instead. Drawing on insights from Goleman and Senge's (2014) *The Triple Focus*, we propose that integrating attention to intrapersonal, interpersonal, and broader social and ecological interdependence can deepen and extend SEL. Practical examples of systems intelligence in action—such as young children using feedback loops to resolve conflicts—illustrate the intuitive nature of this form of thinking. We also show that a variety of practical tools now exist to help educators weave systems science into SEL in diverse contexts. Finally, we situate cultivating systems intelligence within recent educational innovations, arguing that, together, these can enable a transformative educational paradigm that fosters both deeper understanding of interconnectedness and agency in addressing global issues.

Impact Statement: This paper highlights how children's natural systems intelligence—their intuitive ability to see patterns, relationships, and interconnections—works together with social and emotional learning (SEL). SEL skills such as empathy, self-awareness, and perspective-taking can strengthen children's systems intelligence, helping them understand how their actions influence others and the world around them. Using real classroom examples, the paper shows how combining systems intelligence and SEL supports students in navigating complex issues like conflict, community challenges, and climate change. The paper offers practical guidance for educators and clear direction for policymakers seeking to enhance student well-being, agency, and preparedness for an interconnected world.

Introduction

A growing body of developmental research suggests that even very young children possess innate capacities for moral reasoning, altruism, and fairness. For example, Hamlin and colleagues (Hamlin, 2013; Hamlin & Wynn, 2011; Hamlin et al., 2007) found that even infants as young as six months can distinguish between helpful and unhelpful agents and show a preference for those who act prosocially—evidence of an early-emerging moral sense. Similarly, Warneken and Tomasello (2009) have shown that toddlers engage in spontaneous helping behaviors, offering assistance to others without external rewards, suggesting an intrinsic motivation toward cooperation and care. Lucca et al. (2018, 2019) further demonstrated that infants use principles of fairness to guide social decision-making, evaluating how resources are distributed and showing sensitivity to equity. Together, these findings suggest that children are born with an inborn capacity to perceive and respond

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https://doi.org/10.1016/j.sel.2025.100167
Received 17 January 2025; Received in revised form 20 November 2025; Accepted 20 November 2025
Available online 23 November 2025

to patterns of interdependence, fairness, and intentionality in their social worlds—a foundation we describe as *systems intelligence*, or the innate ability to understand relationships, interconnections, and change within complex systems. This capacity is essential for understanding much in life and the nature of learning, and failing to recognize and further develop this capacity constitutes a fundamental shortcoming of the modern education system. This failure contributes to a great many problems of the modern world, from our inability to listen to those with whom we disagree to the destruction of our ecosystems and the planetary conditions for life flourishing.

The purpose of this paper is to point to this blind spot in modern schooling and give a sense of what is possible—for children and educators alike. A great number of counterexamples show what is possible, and there are many relevant learning tools, methods, and pedagogical practices to help us shift course. Like other basic education innovations, however, cultivating children's systems intelligence requires more than just tools and technical knowledge; it stretches the culture and processes of mainstream schools, a practical challenge that must be recognized and addressed for these ideas to have any chance of real impact.

We see cultivating systems intelligence as a close cousin of social and emotional learning (SEL) and believe the two embrace complementary aims and have many potential synergies. Greenberg (2023) argues that SEL emerged in response to basic limitations of mainstream education to address students' declining mental health and behavioral challenges, and the limited capacity of traditional academic instruction alone to equip students for lasting success in school, work, and life. Defined as the process of acquiring the competencies to recognize and manage emotions, develop care and concern for others, establish positive relationships, make responsible decisions, and handle challenging situations effectively (Weissberg, 2019), the aims of SEL overlap those of cultivating systems intelligence. This was first signaled in Goleman and Senge's (2014) book *The Triple Focus*, which argued for a future education system that addresses the intrapersonal, interpersonal, and larger social and ecological realities as three interwoven and inescapable levels of interdependence. Without this broadening of view, we believe today's SEL can easily be lost in important but more fragmented and narrower topics like executive function, emotional regulation, stress management, or anti-bullying strategies. Although important, treating these matters as discrete misses common underlying systemic structures that shape similar dynamics in very different contexts. Conversely, learning how to see such structures and our parts in shaping them can unify knowledge and build life skills in more systemic ways of thinking and acting. In effect, cultivating systems intelligence can provide a common foundation for understanding not only self and other, but larger social and ecological problems, from global migration and poverty to climate change, and to cultivating a sense of agency in engaging with such issues.

This paper makes the argument that, although daunting, cultivating systems intelligence as a foundational feature of child development and learning is both feasible and can contribute to many of the basic aims of SEL educators. Given the transcendent need for greater systems intelligence in our societies, we believe its cultivation should become a priority across ages and subject material. We focus in this paper especially on early learners and primary school because we believe this is the highest leverage strategy given both the brain's malleability in this time and the ease with which young learners take to the types of tools and learning strategies involved—as well as the natural fit with the more open and flexible nature of early years schooling. We summarize applications with older learners at the end of the paper and point to future research areas to further develop this and other facets of this emerging field in education.

What do we mean by systems intelligence and what does it mean to cultivate it?

Notions of intelligence are anchored in "the faculty of understanding" and "ability to deal effectively with new or trying situations" (Merriam-Webster, n.d.; Oxford English Dictionary, n.d.). We regard systems intelligence as that capacity to understand and deal effectively with settings characterized by high degrees of interdependence and change. Like all forms of intelligence that matter to educators, defining systems intelligence in the abstract cannot be separated from seeing what it means in practice and how it is developed or impeded.

Our understanding of children's innate systems intelligence has been shaped by countless examples of the internalization and use of basic systems constructs, such as feedback loops, especially by early learners (Senge et al., 2012). For example, a *self-reinforcing feedback loop* can help explain situations where a small action can lead to consequences that eventually produce still more of the same action. This process can resemble a snowball rolling down a slope: as it gathers more snow, it rolls faster and faster, and gathers still more snow.[1]

Imagine three six-year-old boys after a playground fight. Now imagine them using the language of systems—this is what we observe in an educational video from the Waters Center for Systems Thinking (2018) that we often reference in our work. Without any prompting, the boys used a basic systems tool they had been studying in class to understand why they kept having fights on the playground. When a teacher walks by and asks them to explain, they talk her through a feedback loop they had drawn on a sheet of flip chart paper. The diagram shows "mean words" and "hurt feelings" connected in a self-reinforcing feedback loop—driving a "vicious cycle" in which they have become stuck (see Fig. 1). "First," says one boy, "we have mean words, then we have hurt feelings, and then we have more mean words, and then we have more hurt feelings. Then, a fight breaks out." Another adds, "We have been looking for all the ways we can break the loop." Pointing to a small cross they had drawn on one link of the feedback loop, he says, "We tried saying 'I'm sorry,' and that sort of works." Then he adds (pointing to other markings on the diagram), "These are all the other things we can try the next time a fight breaks out."

We have watched this video with many groups of educators who marvel at the ability of these boys to step out of their emotional conflict and create a simple model to better think together about how they are all part of creating their problems and what they could do differently. For us, watching the boys suggests that they are evoking a quite intuitive way of thinking about a difficult situation we can all identify with, being stuck in a vicious interpersonal cycle like their mean words–hurt feelings loop. But, instead of feeling trapped and even hopeless, they talk matter-of-factly about how they are co-creating this unintended reality, producing a natural sense of possibility for creating a different reality. For

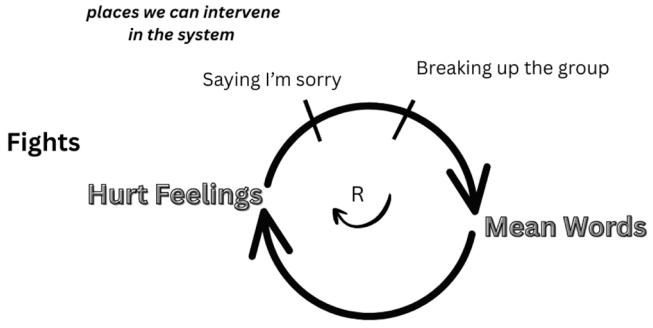

Fig. 1. Reproduction of a self-reinforcing feedback loop diagram on "mean words–hurt feelings" developed by a group of six-year-old children. Note. R = reinforcing loop.

[1] Often referred to in mathematics and engineering as a 'positive feedback' loop.

these boys, the simple feedback loop they drew offers a natural tool to enable reflecting and re-imagining. In our experience, when done collectively, seeing underlying systemic structures we co-create that connect our actions to our reality can lead to lasting change.

What this example illustrates is the learners' ability to conceptualize a challenging situation using a basic systems thinking tool. It shows young children as "model builders," constructing an explanation for themselves of a problematic situation they face (Papert & Harel, 1991; Schulz, 2012; Ullman & Tenenbaum, 2020). And it shows them doing so in a manner that enables them to reflect together in ways that not only illuminate why they are having this problem but alternative actions they could take. Last, the video was created when a teacher walked by and asked, "Can you explain your loop to me"—which illustrates the role of the educator in both shaping the environment and being 'a student' to listen to the children's explanation and give feedback on it. In short, the video illustrates several aspects of the overall pedagogical environment conducive to nurturing systems intelligence:

- Children focus on problems that are real for them and non-trivial.
- Children are encouraged to use basic systems learning tools and concepts.
- A school environment, and educators specifically, are attuned to supporting this type of learning.

This example also illustrates the contributions that systems intelligence can offer within the context of SEL. From an SEL lens, the boys' actions reflected their capacity to engage in several SEL skills as a foundation for navigating their complex social reality. The Collaborative for Academic, Social, and Emotional Learning (CASEL, 2020) offers a prominent model of SEL that describes five areas of social and emotional competence essential for navigating social roles and life tasks (Greenberg, 2023; Osher et al., 2007; Payton et al., 2000; Schoner-t-Reichl, 2023; Weissberg et al., 2015; Zins & Elias, 2006): self-awareness, social awareness, relationship skills, self-management, and responsible decision-making. We can see that the boys engaged in self-awareness through their recognition of the impact of their thoughts and emotions on their own behavior; social awareness through the ability to recognize the commonalities of the experience they shared with that of their peers; relationship skills through their ability to communicate, listen actively, and work collaboratively to problem solve; self-management through their ability to use their feedback loop diagram to step out of the emotional conflict as a form of self-regulation; and responsible decision-making by considering the consequences of their actions on others in a social context and with their collective decision to search for ways out of the mean words–hurt feelings cycle. Although the CASEL skills focus on intra- and interpersonal competencies, through using a tool to identify a systemic structure at play, the students are learning about systemic dynamics that can arise beyond their immediate situation—for example, the 'mean words and hurt feelings' between warring political factions caught in similar vicious cycles of self-reinforcing destructive feelings and actions.

Cultivating systems intelligence also shares the aim of SEL to foster insight and agency. Just as SEL skills can help understand and unfreeze stuck emotions and toxic relationships, cultivating systems intelligence helps students learn how complex social realities can be made less rigid and deterministic. By constructing their system model, knowing the feeling of being trapped in the forces it explains, *and* discovering how their collective reflection and inquiry could shift these forces, the boys have a lived experience of systems understanding and change that can potentially become a point of reference as they encounter other complex "stuck" problems. When one of us saw one of the boys some months later and asked, "How are you three doing now?" he responded, "Oh—we're best friends now" (for video, see Waters Center for Systems Thinking, 2018).

Although we believe this capacity to understand interdependence, diversity, and change is innate, what is not cultivated will not grow. The example above was only possible because the three boys were in an early-years education setting that immersed them in basic systems thinking tools and the sensibilities of systems awareness: reflection, collaboration, discovery, and action. Of course, since Dewey (1938), education innovators have been focused on shaping such environments. What is new here is weaving into innovative education an explicitly "systems worldview:" understanding based on interdependence (rather than unidirectional causality) and dynamic or ongoing change (rather than static pictures of how things are). By contrast, cultivating systems intelligence is impeded by traditional education systems focused excessively on technical fragmented academic content, pedagogies based on win-lose competition, reductionistic understanding of complex phenomena, and focusing on right answers and wrong answers to questions that have little meaning to learners.

Intellectual and academic roots

Although SEL has drawn primarily from academic fields like psychology, and related developmental sciences (Osher et al., 2016), our contemporary understanding of systems intelligence and how it is developed is anchored in a long, multi-faceted arc of Western science bending back toward far more ancient perspectives based on interdependence, including indigenous worldviews and spiritual traditions like Taoism and Buddhism (McMahan, 2008). For example, contemporary Indigenous scholar Andreotti (2020, 2021, 2023) centers much of her current work on "Indigenous entanglement ontology," borrowing a term from modern physics and cosmology. The ceaseless interdependent flow between yin and yang epitomizes the Taoist perspective, and an anchor concept in Buddhism is the illusory nature of a separate self (Epstein, 1995; Ricard, 2010, 2018; Zhang et al., 2024). Although materialism and subject-object dualism have characterized most of Western science since Descartes, this orientation has gradually been shifting. For much of the past two centuries, accounting for complexity and change has become a core concern for more and more branches of Western science. Particular developments in physics, engineering, and biology have shaped our understanding and practice of systems intelligence and its relevance to child and adult development. The following section briefly outlines these developments to highlight foundational concepts of systems intelligence.

Physics: from a Newtonian world of separate things to the modern physics of interconnectedness

In many ways, developments in physics since the start of the last century have been the icon of modern science slowly transiting from fragmented and static views and reductionist methods to ones based in interdependence and change. Capra (1996) argued that the core commonality between the relativistic and quantum revolutions in twentieth century physics lay in a shift of seeing reality from the primacy of things (e.g., Newtonian billiard balls colliding and transferring energy) to the primacy of relationships. "The key characteristic of systems thinking," he argued, "is the shift from parts to the whole" (p. 36). He argued this was especially important to understand living systems: "Living systems are integrated wholes whose properties cannot be reduced to smaller parts" (p. 36). The eminent quantum theorist Bohm (1980) argued that seeing things as separate, such as "me versus you" or "school versus home," does not mean they are disconnected. Failing to see these connections, he suggested, was a primary source of dysfunction in the modern world. "The ability of man to separate himself from his environment," wrote Bohm, although convenient for "thinking about things […] when applied more broadly" to our notion of ourselves and our world leads us to "see and experience ourselves as [*actually*] constituted of separately existing fragments" (p. 2). This habit of fragmentation in our thinking, projected to being an absolute feature of our reality, leads to "losing awareness of what we are doing, extending the process of division beyond the limits within which it works properly" (p. 2). Bohm

believed that as this habit of fragmentation becomes embedded in a culture, it leads to creating a world "that is neither physically nor mentally healthy for most of the people who live in it" (p. 2).

These concerns led Bohm to focus in the later years of his career on "dialogue" (from *dia logos*, literally, "flow of meaning") as a process of reversing this culture of fragmentation and cultivating human cultures of wholeness and interconnectedness—one inspiration for our work on deeper communication and more generative relationships—or *social fields*—in classrooms and schools as we will discuss later.

Systems thinking in engineering: the MIT system dynamics lineage

Applying an understanding of systems to practical engineering problems has been advancing for over two centuries, dating at least to James Watt's flyball governor to control the speed of steam engines. Building on engineering approaches to systems behavior, Forrester (1961, 1969, 1973) at the Massachusetts Institute of Technology (MIT) developed the field of *system dynamics* as a general approach to understanding complex social systems. An accomplished engineer (inventor of radar and core memory, which gave rise to digital computation), Forrester extended the engineering foundations of systems analysis to embrace nonlinearity, a defining feature of social and biological systems (Marino & Frilot, 2003). As important, he focused on the intuitive underpinnings of how underlying systemic structures shape behavior over time based on three canonical elements: multiple feedback loops, stocks and flows (the mathematical concept of integration), and time delays. Today, system dynamics is taught as a discipline-crossing approach to systems model building (for example, computer simulation models and conceptual models) at universities around the world and integrated into many consulting and research approaches (Forrester, 1961). By the mid-1970s, systems dynamics had also been applied to develop well known simulation models of urban growth and the systemic causes of today's sustainability crisis caused by exponential economic and population growth in a world of finite natural resources and ecological carrying capacity (Forrester, 1969, 1973; Meadows et al., 1972).

For us, the more important development started in the 1980s and 90s when the generality and intuitiveness of the systems dynamics approach led a small number of pioneering PreK–12 educators to adapt tools and pedagogies designed originally for college students to approaches that worked for younger learners (Benson & Marlin, 2021; Sweeney & Meadows, 2010). These educators found that even very early learners intuitively understood basic feedback dynamics like the runaway behavior of a vicious cycle (such as the three boys' mean words and hurt feelings feedback loop) or how we enact a simple balancing loop when filling a glass of water by slowing the inflow as the glass approaches being full (Senge et al., 2012). Likewise, by an early age, children can understand stocks and flows, whether through water flowing in and out from a bathtub or money saved and spent from a bank account (Senge et al., 2012). By the 1990s, organizations like the Creative Learning Exchange (https://serc.carleton.edu/resources/14174.html) and the Waters Foundation (now Waters Center for Systems Thinking; https://waterscenterst.org) arose to promote these systems dynamics methods in education and share tools and insights developed by educators.

Living systems, biosemiotics, and social fields

Initially dominated by taxonomies and building elaborate specimen collections, it was not until the twentieth century that the field of biology began to develop a robust focus on ecological life and living systems. Interestingly, it was scientists immersed in the budding worlds of cybernetics and systems biology like Humberto Maturana and Franciso Varela who led the way. Foundational ideas like "autopoiesis" led to a more rigorous notion of what constitutes a living system as a system that creates itself—i.e., is *auto* (self) *poiesis* (creating)—versus one that is created by another, that is *allo poiesis,* like a machine (Varela et al., 1974). As ideas like autopoiesis became established, biology came to regard self-creating living organisms as existing within nested and layered ecological and social systems (Bronfenbrenner, 1979). Urie Bronfenbrenner, Kurt Fischer, and others advanced how we see humans developing within complex environmental contexts, shaping dynamic skill development across one's lifetime (Fischer & Bidell, 2006). A branch of biology that has been especially meaningful for us is biosemiotics, which studies communication and meaning making among social species. Pioneers in this field like Hoffmeyer (1996) argued that failing to see meaning making as a common feature of diverse species led humans to systematically delegitimize other species and sanction damage to natural ecosystems. Such critiques became an inspiration for some of us to study meaning making in nonhuman species—which, along with Bohm's work on dialogue, became a key to our understanding of generative social fields, the energetic and emotional qualities of a relational space that can help the self-creation of a given system (Boell et al., 2025) (as we will discuss below in the "compassionate systems" approach).

Although the concept of systems has powerfully shaped developments in physics, engineering, and biology, it can take centuries for a new scientific worldview to become embedded in society and mainstream education, and our modern world is still shaped far more by seventeenth century physics than the emerging science of interconnectedness. The result is that low relational and systemic intelligence pervades all aspects of modern society, creating diverse consequences rarely seen as arising from a common source—from loneliness and purposelessness to polarization and repression of diversity, to destruction of ecological integrity, and, most important here, an inability to understand and develop systems intelligence in our culture. But quietly, a small but growing number of outliers in education have emerged—diverse exemplars of the practical possibilities of developing system intelligence in mainstream education.

Children as systems thinkers and sensors: pioneers in weaving systems into early years education

Many great scientists are drawn to their work at a very early age. When asked how he became a physicist, Victor Weisskopf, former head of the Physics Department at MIT and a member of the Manhattan Project, said, "As a little child, I used to love to sit under the grand piano as my grandmother played. That's when I became a physicist." As Weisskopf's story illustrates, cultivating systems intelligence encompasses both systems thinking—cognitive or conceptual skills—and systems sensing—a multisensorial feeling of our awareness of interdependence. In this next section, we explore three examples (Reggio Emilia, systems thinking in primary years, and Compassionate Systems) where children's curiosity, exploration, collaboration, and play become vehicles for developing their understanding of interdependency and connection, and make connections to how they relate to the competencies of SEL.

Reggio Emilia

Reggio Emilia has inspired early learning educators for decades and influenced early childhood education policies around the world (Rinaldi, 2006). Although the term systems intelligence is rarely used directly, for us, the heart of the Reggio model comes from the power of honoring children's direct experience of the interconnectedness inherent in the social and natural world.

After the Second World War, the Women's Union in Reggio Emilia, a small city in Northern Italy, decided that to prevent fascism from ever arising again, children needed to be educated in a way that would foster democracy, starting from small infant and preschool age. In 1946, Loris Malaguzzi helped them form their first preschool, which, over the next twenty years, grew into a network of infant-toddler and early childhood learning centers throughout the region, including the first municipal preschools established by the Reggio Emilia town council in 1963

(Cagliari et al., 2016). Malaguzzi's vision was an educational approach that would foster children's creativity, critical thinking, and social responsibility anchored in a profound view of the child's capabilities.

Central to this approach is the *hundred languages of the child*, honoring understanding and expression not merely limited to verbal voice and cognitive reasoning but including music, art, and dramatic expression (Reggio Children, n.d.). A core idea in the approach is that children are the center of their own learning and the initiators of the process. Malaguzzi observed that the ingrained and natural interests that children have inspires them to learn and construct their own unique best way to learn (Cagliari et al., 2016). He viewed children as being full of potential, as capable, curious, and competent learners. Relating this to SEL, this approach supports children's development of self-awareness, including their emerging interests, confidence, and a sense of purpose. Malaguzzi also believed that collaborative play was important for developing social skills and empathy, which aligns directly with the SEL competencies of social awareness and relationship skills. Indeed, at the heart of his philosophy, Malaguzzi saw play as the basic language for exploration, expression, and communication.

In Reggio Emilia, collaborative play grounds awareness of social interdependency, which then extends to continuous interactions between all those involved in the school community. Collaboration takes place between teachers and children, children and peers, teachers and other teachers, teachers and families, the school and the larger community—and this becomes the model for learning how the world works, and for fostering relationship skills, one of the key competencies of SEL. A wonderful example one of us observed in a Reggio setting arose when the children asked, "Where does the rain come from?" Rather than being "taught" the answer, this question led to a cooperative exploration of the water cycle: being outside and observing rain, evaporation, cloud formation, thunder and lightning, and then expressing all this through art, dance, and collage. The children clearly saw the world and their place in it and their interconnectedness to how water moves through its many forms and uses. This illustrated the core Reggio philosophy that children learn best through how their own questions can lead to experiencing learning in all its many variations, rather than being told what they should learn (Cagliari et al., 2016).

This attention to interrelatedness shows up also in Reggio's emphasis on the quality of listening and documentation of children's work by educators. Studying Reggio, Carlina Rinaldi explains listening "as sensitivity to patterns that connect, to that which connects us to others; abandoning ourselves to the conviction that our understanding and our own being are but small parts of a broader integrated knowledge that holds the universe together" (Project Zero & Reggio Children, 2001, p. 80). To do so requires Reggio educators to cultivate their own systems intelligence, to become aware of their own connections to their students and the environment as they listen, observe, document, and assess a learner's development. Reggio educators also focus on children's expression of this interconnectedness, a pedagogical principle that one of us witnessed recently in a setting far from Reggio's Italian origins. In a school visit in Ontario, Canada, one of us watched Reggio educators practice "documentation"—to capture, express, and share ideas that matter to students. One such documentation practice yielded a simple statement expressed by the children on the idea of kinship which beautifully summarizes interconnectedness as experienced by early learners, "living well and being together" (see Supplementary materials S1). Through this example, we can observe that this attention to interrelatedness in the Reggio approach fosters the SEL competency of social awareness not only in children, but also in educators as they empathize with learners, and their documentation and communication of the learners' ideas in a way that resonates with the students. Although Reggio is not framed in the language of SEL, the approach naturally cultivates SEL by fostering emotional expression, relationships, collaboration, and reflection.

Systems thinking approaches in primary years

Although innovative communities like Reggio Emilia have influenced early learning pedagogy around the world to embrace self-directed play and experimentation, once students advance past kindergarten all too often pedagogy reverts to the traditional teacher-centered, passive-learner model (Resnick, 2018). With this, the natural immersion in interdependence is lost. As Malaguzzi wrote, "The school and the culture separate the head from the body" (Reggio Children, n.d.). Although the learning process naturally needs to change as children get older and have different developmental needs, the focus on social and ecological interdependence does not. The social complexity of primary school-age learners' lives can be overwhelming as they navigate family, school, social relationships, and community life. Anxiety over global dangers like poverty and climate change represent a new source of stress and anxiety, even in primary years. A recent study published in *Nature* talks about how "children *and* adolescents may be uniquely predisposed to climate anxiety" (Crandon et al., 2022, p. 123). Although SEL may offer students the basic intra- and interpersonal competencies they need to cope with such anxieties, such systemic challenges require systemic responses—equipping young people with ways to understand their social and ecological interdependence so they can develop agency and efficacy in navigating this complexity.

We believe the core problem is not need but know-how. Even though many educators recognize how these extraordinary challenges are affecting their students, few feel equipped with strategies and tools for cultivating systems intelligence. This is exactly what drew a group of early childhood educators to the MIT lineage of systems thinking. They saw that the basic epistemology of system dynamics was intuitive to learners from an early age (Sweeney & Meadows, 2010). For example, the *systems thinking iceberg* (Perrenoud, 2020; Senge et al., 2012) is a tool that helps us distinguish "events" (the tip of the iceberg above the water) from "patterns of system behavior" over time that give rise to the events, and from "underlying structures" (deep below the surface) shaped by mental models and artifacts that are the source of those behavioral patterns (Cunliff, 2018; Senge et al., 2012). From the age of five or even earlier, young learners have little difficulty distinguishing an event like a fight on the playground from a pattern of behavior over time that gives rise to the event, like increasing anger and hostility between two children over time. It then becomes natural to start asking, "Why do these patterns occur?" which can lead to insights into underlying structures like the three boys' mean words–hurt feelings feedback loop we described above.

Creative educators found that tools like the systems thinking iceberg blended naturally with pedagogical philosophies like constructivism, that is, how we humans develop our own theories to explain what we experience. Echoing Malaguzzi, Jean Piaget, Seymour Papert, and many others (Cagliari et al., 2016; Papert & Harel, 1991; Powell & Kalina, 2009), these educators saw children as natural "model builders" and taught them how to use the basic system dynamics tools to create, share, and test their own theories of systemic causality, thereby also introducing the basics of scientific inquiry in an intuitive and engaging way at an early age.

From the system dynamics tradition, cultivating the systems intelligence of children has become operationally defined by their facility to (1) recognize and express patterns of change over time, (2) use feedback loop diagrams to illustrate their intuitive grasp of reciprocal causality and (3) employ stock-and-flow diagrams to understand accumulation and time delays. Like the systems thinking iceberg, *stock and flow diagrams* express a deep intuition about systems present from a very early age. For example, children notice how their pile of building blocks (the stock) grows as they add more pieces and shrinks as they take pieces away (the flow). Such daily observations are critical in helping young learners grasp the concept of accumulation and depletion, forming a foundational understanding of basic system dynamics. Observing early years learners play with water and sand offers frequent moments to

witness the attempts of children to accumulate a stock, distribute it, and preserve it, an understanding they can easily transfer to more intangible subjects.

Together, these system dynamics tools offer an intuitive foundation for understanding the systemic causes of change over time in all manners of systems—from family dynamics to climate change, which can enrich basic SEL instruction so that learners can better navigate these complexities. This systems understanding, which comes naturally to early learners, however, can often elude adults not trained in the basics of systems. For example, research has shown that adult MBA students typically erroneously believe that stopping growth in greenhouse gas (GHG) emissions will stop rising global temperatures because they fail to distinguish emissions (a flow) from the concentration of greenhouse gasses in the atmosphere (a stock). This leads them to significantly underestimate the time it will take to stop global climate change, a misunderstanding that has contributed to why many adults feel far less urgency about climate change than do climate scientists (Sterman & Sweeney).[2] By emphasizing intuitive building blocks like patterns of change, feedback loops, and stocks and flows, system dynamics adds a technical and mathematical dimension to the intuitive and aesthetic understanding of interdependence as embedded in methods like Reggio Emilia (Senge, 2006).

Compassionate systems: weaving inner and outer complexity

The Compassionate Systems Framework aims for a fuller development of "systems awareness" by augmenting the MIT system dynamics tradition of practical tools for systems thinking with an emphasis on emotional intelligence, relational competencies, and contemplative practices (See Supplementary materials S2 for tools and practices in the Compassionate Systems Framework). Developed over the past decade as a synthesis of system dynamics, a biological understanding of living systems, SEL, the science of wellbeing, and diverse mindfulness traditions (Boell et al., 2019), the Compassionate Systems Framework supports developing learners' capacities for *systems thinking*—the skills for conceptual understanding of systems—and *systems sensing*—how we perceive and experience systems, such as their awareness of the quality of social relationships and how they can be nurtured (Boell et al., 2019, 2025). As humans, we have gifts in both domains of systems thinking and sensing, and it is easy for them to blur in our normal ways of operating. But for educators, understanding the two and their interplay is important for effective pedagogical strategies. For example, systems sensing concerns how our whole mind-body system connects with its surrounding, helping us access and understand our lived experience in any complex context. In systems sensing, we might ask, "What's the feeling? What's the atmosphere? What's the quality of the relationships that I'm in? How does it occur to me sensorially (bodily sensations, smells, sounds, tastes, visual details) and emotionally?" These emotional and somatic capacities, which are also cultivated in much of SEL instruction, paired with the conceptual understanding of system dynamics, enables us to attend to and understand holistically the social, emotional, and somatic experiences we have within complex systems.

In the compassionate systems approach, the two, systems thinking and systems sensing, are seen as inseparable ways of knowing, a sort of binocular vision for complexity. Just as thinking and feeling are both always present in human perception, we both understand systems conceptually and encounter them sensorially. This makes cultivating systems intelligence from the compassionate systems approach inescapably an "inner" and "outer" journey, embracing both cognitive or conceptual dimensions and reflective and enactive dimensions, harkening back to Reggio Emilia's emphasis on the artistic as well as verbal and analytic expression of how we understand interconnectedness.

Taking this reflective dimension seriously is radical and can challenge students and educators alike. It is one thing to identify cultural forces shaping our social reality; it is another matter to see how, I, myself, embody those mental models and, in so doing, open myself to the deeper learning processes needed to shift those that are problematic (Cook et al., 2021). This is another reason to start with younger learners so to develop the reflective muscle to understand how they are shaped by and in turn shape their cultures and communities.

Just as they display natural predisposition to systems thinking tools like feedback loops and the systems thinking iceberg, young children also have an innate openness to building relationships with each other. For example, Thiele et al. (2021) found that between 7 and 13 months, infants increasingly prefer social interactions over non-social activities, demonstrating early sensitivity to and engagement in social relationships. Continuing to cultivate this relational capacity is key to nurturing children's systems intelligence as they take responsibility and care for the relationships within their given system, whether in a family, classroom or on the playground.

In practice, a key idea in the compassionate systems approach is the quality of a "social field" in classrooms, schools, families, and communities (Boell et al., 2018; Boell & Senge, 2016). In a sense, the terms *social system* and *social field* are seen as natural complements to understanding a complex social reality. Seeing a social reality as a *system* is looking at it "from the outside" in the sense of conceptualizing and analyzing the forces at play in a particular setting, like the three boys seeing themselves caught in the reinforcing loop of mean words and hurt feelings. Reflecting on the quality of the social field also means viewing that reality "from the inside" in the sense of people's lived experience within such a setting (Herrmann, 2023). Like systems thinking constructs such as the systems thinking iceberg, the idea of the quality of the social field taps deep intuitions children have of their lived experience of a social setting. Compassionate systems tools and practices, like the dialogic Check-Ins and Stock and Flow tools we discuss below, help connect the two—bringing the inner and outer experience of the system together in our sensemaking (Boell & Senge, 2016). Attending to the systemic forces at play (e.g. racism or structural inequalities) *and* the quality of the social field (e.g. sense of trust) people experience adds depth to understanding a complex reality and to meeting the challenges of ongoing systems change. Lacking the two inevitably thwart change efforts based in purely rational analysis and political power (Scharmer, 2016).[3] Trust and a sense of connectedness matter practically, not just personally. In short, the quality of the social field influences our inner emotional landscape and the ways we "show up," which in turn influences the forces at play in social systems. In the compassionate systems approach, attending to the quality of the social field guides work in classrooms, schools and beyond, nurturing spaces that enable students and communities to feel safe, seen, heard, and empowered and where they can explore who they are, how they are in relationship with others, and what they want to create (Cook et al., 2021).

As classroom educators, the concept and practice of cultivating social fields offers a simple way to attend to the container for learning, or how we are creating conditions conducive to learning. One such pedagogical practice used widely in the compassionate systems approach for developing this container is the structured reflective conversation protocol called a "Check-In."

[2] In fact, it is the GHG concentration that determines the rate of 'thermal forcing" and gradual increase in the global mean temperature, and GHG concentration, which has been rising since the start of the Industrial Age, will only start to decline when GHG emissions peak and decline until they become *less than* GHG removals from the atmosphere. Present estimates are that which will require more than a 50 % reduction in emissions, which will take much longer than just stopping emissions growth (Sterman & Sweeney).

[3] For example, a famous study by management consultancy McKinsey found that, in business, "70 % of change management programs fail to achieve their goal"; diverse studies in the field of quality management likewise found two-third or more of change programs failed (Ewenstein et al., 2015).

Check-ins

Check-ins are commonly used in systems thinking approaches to help students reflect on relationships, interconnections, and the dynamics within their learning environments. They are also a simple and widely used SEL practice that can be implemented from kindergarten through high school and beyond to foster a sense of belonging and ensure that every learner feels heard and welcomed (Edutopia, 2023). In its simplest form, the protocol involves two or more children in a group, each taking turns to answer a reflective question, such as "What am I feeling as I enter class today?" while the others listen attentively without interrupting. Participation is voluntary, but in our experience, nearly every child has something to share. When practiced consistently over time, this approach helps establish a classroom norm in which all voices are equally valued. Although teachers might wonder where they get the time for such a practice, our experience shows that when they become a core routine, check-ins can help build a classroom climate of greater calm and attention that enables more effective and efficient use of teaching time in diverse cultural contexts (See Supplementary materials S3 on different Check-In systems designed by students).

Stocks and flows

As children experience first-hand a more generative social field through *systems sensing* tools like Check-Ins, they are eager to use more conceptual *systems thinking* tools like "stock and flow diagrams," especially when initially used for personal reflection and sharing. The simplest version of the Stock and Flow tool involves an inflow, a stock that can increase or decrease, and an outflow. Using a bathtub metaphor helps students (and adults) visualize this tool more easily (see Fig. 2). Taking an example like happiness or sense of well-being, children enjoy identifying factors that when present cause the stock to grow and likewise those that can cause the stock to drain. At Dulwich College, a primary school in Singapore, stock and flow diagrams were used in an early years' environment at the beginning of the school year around the pivotal question: "How do we create a thriving classroom?" The students work together to generate a list of elements that can be inflows to the stock of a "positive social field in the classroom" and things that create outflows draining the stock. This approach offers a sharp contrast to the traditional model of teachers telling students the classroom rules. It also lays a foundation for understanding the dynamic reality of the classroom, of the ever-changing variables that might grow and erode a positive classroom social field. This also shows how systems thinking tools can help build students' agency in cultivating a supportive learning context—one of the core three dimensions of SEL— along with students' and educators' SEL (Schonert-Reichl et al., 2017).

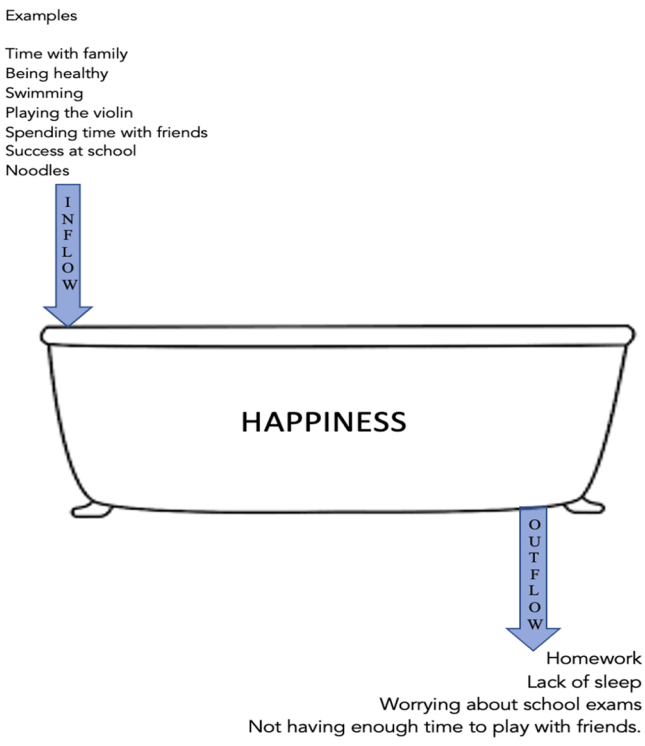

Fig. 2. Stock and flow diagram produced by primary school students using a bathtub metaphor. Note. The language used in the diagram reflects students' personal expression.

Across these examples, we also find that for students who have barriers to writing or are English Language Learners (ELL), pedagogical tools like stocks and flows, feedback loops, or a visually expressive Check-In afford more accessible visual mediums that helps students regardless of background build confidence in their ability to understand complex issues and recognize the impact of their actions.

As constructionist educators have long maintained, children are innate model builders and, given the tools and practices, will use diagrams like the stock and flow diagrams to explore and advance their systems understanding, first as a way to express their understanding and then to explore how they and others experience a complex reality (see Supplementary materials S4). Educators can then gradually introduce more complex systems thinking concepts like feedback loops and system archetypes like "fixes that fail," when an intended fix also has unintended negative side effects, and "shifting the burden," when a quick fix can supplant a deeper and longer-term improvement. Used in this way, the systems thinking tools offer a natural progression of basic linguistic constructs, vehicles to both express and develop young learners' systems understanding and fluency. We believe studying this progression could be a fruitful research domain.

When combined within the compassionate systems approach, this type of model building applied to real ecological and social issues not only enhances conceptual and analytical skills but also encourages empathy and allows students to acknowledge and support one another as they confront the emotional *and* technical complexity of genuine societal challenges. Much like the Reggio philosophy discussed above, this can become a powerful way to ground the interdependent development of systems thinking and systems sensing in service of understanding and expression.

As educators build their own fluency with the basic language of systems and the art of shaping more generative social fields through emotional literacy and relational practices, they and their students can then explore increasingly complex real world issues phenomena, even with younger students. At the International School of Zug and Luzern, in a unit on international migration, elementary students aged seven used stock and flow diagrams to understand the dynamics of migration, including "push" and "pull" factors affecting migrants and host communities (Boell et al., 2019). During the unit, students engaged in simulations and role-playing, complemented by drawing stock and flow diagrams and behavior-over-time graphs showing how key variables change over time. This approach helped them visualize how changes in migration policies could affect the flow of refugees and the subsequent impact on a country's resources and social fabric. Check-Ins and other reflective tools from the compassionate systems framework complemented and fostered a deeper understanding of the personal complexities of migration and enhanced students' empathy towards migrants, refugees, and the countries into which migrants move, facilitating a multi-perspective view on a very real global issue. The exercise was also a good example of how systems intelligence enhances SEL by integrating systems tools with emotional insights, enabling students to better navigate complex social issues with both empathy and systemic understanding.

Extending the work to middle and high school students

As we have tried to illustrate, cultivating systems intelligence is a

natural process for early learners who are still connected to their innate orientation to interdependence and change. The basic ideas are no less relevant for older students who are confronted head on with the extraordinary complexities of today's world. For all ages, effective pedagogies come from understanding basic developmental needs. For early learners and primary-age students, it is reaffirming their instinctual systems thinking and systems sensing skills, their orientation toward relationships, and fostering confidence that they can learn together with others. For secondary school-age students, successful strategies for cultivating systems intelligence need to be anchored in the complexities of the students' social realities and their awakening sense of concerns about and responsibility for the larger systemic problems they see in their families, communities and society. But, in doing so, the same basic toolkit can be used.

Over the years, we have seen innovative systems educators immerse secondary school learners in a variety of curricula based on grappling with complex practical problems that have no simple right-wrong answers. For example, in one of the first middle schools dedicated to systems thinking, an eighth-grade science teacher designed his year-long class around his students helping to design the trail system for a new state park. After teaching the basics of the systems thinking iceberg and other systems tools, the students used a system dynamics simulation model he had developed to study the economic and environmental impacts of different possible trail designs. Visiting the classroom, two students shared a debate they were having between two design options—one of which routed hikers past a beautiful vantage point across ecologically sensitive terrain, which generated considerable simulated revenue, versus a second that was less costly to build but also less visually spectacular and less remunerative. Eventually a third student joined the debate and said that she too had been drawn to the vantage point trail but did more research and found that there was a tribal burial ground close to that proposed route. At the end of the year, student teams from the class presented their ideas to the state parks commission. The teacher's aim was for his students to wrestle with complex trade-offs where science could offer guidance but for which they would also have to confront value-laden issues where there were legitimate differences of opinion. He also pointed out that end-of-year science test results were as good as or better than those from his prior, more traditional classes, and that student engagement was much higher. This example illustrates how systems thinking tools can be integrated with SEL in solving real-world problems that require learners to consider ethical standards and safety concerns, facets of the SEL competency of responsible decision-making.

For us, cultivating systems intelligence in secondary education starts with recognizing that for most of human history, societies have had diverse ritual "rites of passage" to signal and support the onset of adulthood. One fundamental developmental need addressed by these rites is to catalyze a lifelong journey of discovering one's own distinctive sense of purpose and intent to contribute as a member of an adult community. That this developmental threshold is largely ignored is a tragic blind spot in modern education. Cultivating systems intelligence in older students means engaging them in genuinely meaningful learning that fosters agency around issues that matter to them and their community, which is why collaborative project-based learning and youth leadership are key facets in the compassionate systems work today around the world.

We have found that students are often more ready for this than adults. At another of the early systems thinking-oriented schools in a different city, we found an example where three young students came to their middle school teacher deeply concerned about climate change, wondering what they could do. The result was a project where he mentored them for the rest of the year and eventually resulted in the student team planning, designing, and raising the money to build a vertical wind turbine at their school—engaging a good number of parents along the way as advisors. At an end-of-year school assembly, one of the twelve-year-old students concluded her ten-minute presentation on the project (complete with photos of the turbine now under construction) by looking at the larger adult audience and saying, "We kids are always hearing that, 'You are the leaders of the future.' We don't like that. We don't have enough time to wait for the future. We can be leaders now. We are ready—are you?"

Cultivating systems intelligence can be especially meaningful for young people feeling isolated facing systemic barriers. In southern California, recently, a group of high school-age students used the systems thinking iceberg to analyze the challenges posed by increasing numbers of migrants from Mexico and Latin America in their communities, for both individual families and community infrastructures like schools and healthcare. They concluded that what makes these problems seem impossible to address is people seeing only the events and neglecting mental models regarding migrants. As one young man observed,

> "When people can see us as people who have had to flee unlivable circumstances, there are possibilities to work together. But if they only see 'unwanted immigrants' we all remain stuck. The problems we all face are really big, but they are not impossible."

In this example, systems thinking tools enhance SEL by merging empathy with mental models, allowing learners to take the perspective of others and view the issue through a systems lens, thereby increasing their capacity to generate solutions that may work for all. Cultivating systems intelligence highlights the role of each of us in influencing the systems in which we live, a cornerstone to fostering leadership, agency, and reflective practice. In concert with pedagogies like problem-based learning (PBL), students can be encouraged to take ownership of their learning and to act as collaborative leaders, developing their sense of agency through helping shape more generative social fields that can work together toward systemic change. Through such learning, students can come to deep intuitions that human systems are not just mechanical or driven by forces outside themselves but can be influenced by their commitment, engagement, and understanding.

Last, most educators confronting the global crisis of stress, anxiety, and teenage suicides find themselves stuck at the "top of the iceberg," paralyzed in reaction mode.[4] Sitting behind the "Wellness Centers" in Ventura County, California is a simple systems insight: kids helping other kids also help themselves. In a recent gathering of young people who have been wellness peers for several years, a young woman shared, "The other day I ran into a kid who is a real delinquent type—drugs, gangs, that kind of stuff. I felt like I could be a friend in that moment… I could help that kid in that moment. Just knowing you can help someone makes a big difference." The Wellness Center strategy has proven sufficiently promising that it has expanded to almost half of the more than two hundred schools in the county in five years, with a commitment to compassionate systems core to the county's approach.

Cultivating systems intelligence inescapably rests on reflective practice like we see in these examples. Conceptually, this is anchored in the systems thinking iceberg and the very view of social systems as being shaped by both "artifacts" (e.g., metrics, policies and rules, formal structures) and "mental models" (habits of thinking, feeling, and acting), which always operate in concert. In effect, there is no *system* outside of the participants who help shape how the system actually functions. Experientially, this means that cultivating systems intelligence and continually reflecting on one's role and impact within a system are two sides of the *same* coin— from the classroom to the family to larger social systems. As such, reflection on one's role and influence within a system—an essential aspect of SEL's self-awareness—positions systems intelligence as a natural extension to SEL by linking participants' insights with systems understanding and collective agency.

[4] Suicide is now the third leading cause of death among 15–29 year olds according to the World Health Organization (2024).

How cultivating systems intelligence relates to SEL and other domains of innovation in education

With its focus on relatedness, experiential learning, and social systems, cultivating systems intelligence complements many other areas of educational innovation, starting with SEL as illustrated throughout this paper. As supported by several decades of theory and research, SEL intrapersonal and interpersonal competencies are central to high quality education, simultaneously reducing problem behaviors and aggression and contributing to well-being and academic achievement (Cipriano et al., 2023; Domitrovich et al., 2017; Durlak et al., 2011). These positive outcomes also have been shown to be durable over time (e.g., Taylor et al., 2017).

In practice, the commonalities between SEL and cultivating systems intelligence start with the "system of self," the complex mind-heart-body whose health and well-being ultimately depend on the functioning of the whole, not its fragments. Self-awareness, emotional literacy, and somatic awareness are in some ways the base of systems intelligence because the self-system is always there for us —"wherever we go, there we are," to paraphrase the famous Kabat-Zinn (1994) statement. For SEL practitioners, relating SEL to systems intelligence can also help students see unity among self, other, and larger systems. Moreover, although both empathy and perspective taking are seen as central to SEL (Schonert-Reichl, 2023), cultivating systems intelligence could further clarify the specific affective and conceptual skills needed to do this well—that is, to "see" a system from multiple perspectives, legitimating the knowledge of diverse stakeholders within a system. Lastly, the expansion of responsible decision-making to include tools like the systems thinking iceberg helps in unpacking systemic causality, which when coupled with emotional tools, can help individuals manage their own anxieties that arise in the process of addressing deeper interpersonal and societal issues.

More recently, Jagers et al. (2019) have argued that an expanded SEL includes critical examination of deeper causes of racial and economic inequities to foster an engaged citizenship, and today's systemic SEL emphasizes the contextual and bi-directional influences shaping child development, including Bronfenbrenner's bioecological model of human development (Bronfenbrenner, 1979; Bronfenbrenner & Morris, 2006). Adult development and the leadership challenges of teaching and learning, and family involvement (Floman et al., 2024; Mahoney et al., 2021) likewise align closely with systems intelligence approaches like compassionate systems. Although once seen as a problem of delivering a curriculum, effective SEL today demands that educators take a more comprehensive approach to creating a safe, caring, and well-managed environment that supports both student and adult well-being in order to implement SEL sustainably (Schonert-Reichl, 2017; Zins et al., 2004).

Both SEL and systems intelligence also highlight the importance of leadership at all levels within education systems. Recent work in SEL has highlighted the role of school leaders in promoting systemic SEL, such as the Mahfouz et al. (2019) model of the prosocial school leader that shows how principals' social and emotional competencies, well-being, and leadership form a foundation that influences overall school climate, teacher functioning and well-being, and family and community partnerships—and how these all mediate school climate and student outcomes. The practical challenges of cultivating systems intelligence in diverse settings have led to defining *system leaders* as people skillful at fostering collaboration for ongoing systems change, regardless of their positions of authority and the skills involved (Senge et al., 2015).

In brief, SEL provides the emotional and interpersonal foundation that supports the development of systems intelligence, whereas focusing on systems intelligence explicitly can provide the lens and additional tools that enable individuals to navigate and influence complex social systems with greater awareness, empathy, and effectiveness.

We expect, as SEL evolves, to see more new initiatives that explicitly focus on cultivating systems intelligence. One known first-hand by the authors is the Social, Emotional, and Ethical Learning program (SEE Learning; https://seelearning.emory.edu), developed by Emory University with support from the Dalai Lama. SEE Learning is a K–12 evidence-based program of curriculum and teacher development that emphasizes awareness, compassion, and engagement. With a basic curriculum that has now been translated into 23 languages and implemented in over 59 countries, SEE Learning explicitly integrates interdependence, common humanity, and systems thinking to enhance well-being and foster positive social interactions. Integrating reflective practices, perspective-taking, and ethical decision-making, students are encouraged to recognize complex relational dynamics and act compassionately within their communities, aligning closely with the principles of systems intelligence.

Beyond SEL there are many other areas of education innovation that are closely linked to cultivating systems intelligence. For example, as illustrated above, it is hard for any serious approach to systems intelligence to not build on problem-based learning (PBL) and learner-centered approaches. Going back to pioneering educators like Kilpatrick (1918, 1921) and Dewey (1938), PBL's emphasis on practical problems to promote active learning, student agency and motivation also, if done well, leads to confronting complexity. Stripped of the artificiality of so many classroom exercises, focusing on problems that truly matter to the learner leads to encountering the social and substantive complexity of real life, even to seemingly mundane matters like fights on the playground. Similarly, the center of learner-centered pedagogy is that "Who we are as people matters" (Fullan et al., 2017, p. 27). Once educators confront the inescapable subjectiveness of understanding complexity, they surrender the "naïve realist" view (Maturana & Varelea, 1992) that there is one and only one truth about any complex systemic phenomenon. When trying to understand truly complex matters like climate change or the migration crisis, they must move beyond a rigid objectivist "this is how the system works" view and help learners develop their own views and understanding.

Cultivating systems intelligence: future directions for research and practice

In this review, we have argued for cultivating systems intelligence as a transcendent focus for education, but there is much to be learned about all facets of the picture laid out above. Although education innovators have been busy showing what is possible, often adapting sophisticated ideas from systems science, engineering and diverse scientific domains, cultivating systems intelligence is a largely uncharted territory for education research.

We believe that the most important research focuses on the most pressing needs. With that in mind, we identify three broad areas of research priorities for cultivating systems intelligence: equity and inclusion, youth engagement and activism around key global issues like climate change and migration, and re-envisioning and re-creating schools as learning communities that foster systemic well-being for students and adults alike. For each, we offer a few illustrations of the types of research we think could have an impact and summarize transcendent research opportunities that cut across all three areas.

Together, these constitute a radical view of education as an integrating institution in these divisive times, one that could—in coming generations—become a safe space for inquiring together into the systemic sources of the social and ecological imbalances that plague modern societies and learning how we can evolve better ways of living. "School" in this larger vision connects us all around the well-being and development of our children and young people and shaping the societal conditions that nurture that well-being.

Equity and inclusion

In the U.S. particularly, no education issue is more pressing than recognizing and addressing the structural sources of inequity in educational opportunity and creating learning environments that work for

diverse learners. Cultivating systems intelligence in concert with methods like SEL, project-based learning, and learner-centered pedagogy can develop agency among learners and create a more balanced playing field for all. Specific future research studies could examine strategies for creating more equitable classrooms by examining practices like Check-Ins and their impact on learning environments. One line of inquiry could involve case studies investigating how regular Check-Ins contribute to a more welcoming classroom atmosphere by honoring each student's unique context and strengthening interpersonal relationships. Researchers might also explore how such practices shape a more generative social field, fostering deeper listening that goes beyond surface-level communication and cultural norms, and how students perceive these interactions over time.

Additionally, future research could examine how inherited cultural stereotypes evolve as students develop a deeper systemic understanding of one another's backgrounds through structured Check-Ins. Longitudinal studies could track changes in students' attitudes and relational dynamics, assessing whether increased context-based understanding leads to reduced stereotyping and enhanced inclusivity. These investigations would provide valuable insights into how specific classroom practices can promote equity, empathy, and stronger social bonds among students.

Potential research studies could also explore how educators focused on cultivating systems intelligence use visual learning tools like systems mapping, the systems thinking iceberg, behavior-over-time graphs, system archetypes, and the ladder of inference to support systemic inquiry. Case studies could examine how these tools reduce the reliance on spoken linguistic competence while fostering higher-order thinking skills. This approach may also benefit students who naturally lean on visual intelligence and those from different linguistic backgrounds, such as ELL learners in U.S. classrooms. Research could investigate whether such tools enhance comprehension and engagement across diverse student populations.

Another promising research area involves "warming the data" (Bateson, 2017) through the integration of systems thinking and systems sensing tools. Studies could explore how contextualizing data-based assessments through these tools helps better understand learners' unique contexts while avoiding simplistic, categorical analyses that may reinforce biases. For instance, research could examine specific ways district staff organize and present data so as to highlight context-specific insights, supporting more reflective and compassionate conversations among educators, parents, and students. This line of inquiry could reveal how data-driven practices, when paired with systems sensing and thinking, facilitate more equitable and supportive educational outcomes.

Youth engagement & leadership around global issues

Students and educators alike are deeply concerned about issues like climate change and growing international migration. Yet, few educators have strategies for engaging students in both the substantive and emotional complexity of such issues and helping them develop their sense of agency. Obviously, individual actions do not shift global issues, but ignoring or disregarding the issues as serious matters for education reinforces a sense of hopelessness.

As the school case studies and examples we highlighted above show, innovative educators find many ways to use systems learning tools to create meaningful substantive engagement and safe spaces where students can both learn about the systemic sources of such issues and honor the difficult emotions (fear, anger, betrayal) that arise without allowing themselves to be overwhelmed by these emotions. Future research in this area can include case studies of cultivating student agency. Educators often fear that students will be depressed by having a deeper understanding of systemic issues like climate change and migration that appear to be worsening, but we have heard students report the opposite—that understanding the complexity from a systemic viewpoint motivates them to be more engaged. It also dissolves the fantasy that "adults are in control" of the situation and reinforces the understanding that systemic change can only arise from diverse sources of leadership.

How can we better understand this journey of awakening and its implications for curriculum and pedagogy? Research in this area could include cross-cultural studies of common systemic issues like international migration and climate mitigation and adaptation—for example, case studies where similar tools are used in different cultural contexts and students are then connected to share their insights and feelings. Studies could explore how global communities of practice use and adapt common tools to diverse contexts. Our experience in diverse cultural contexts suggests that learning tools of the sort illustrated here can form the basics of a common language of inquiry and relationship building around common issues. Case studies of global insight and local action could include tracking, cataloguing, and connecting students' activities to systems learning tools, translating insights into local action, and examining how that deepens their systemic understanding.

Developing schools as systems learning communities

Countless education reform efforts have suffered from assuming that innovative curriculum and pedagogy can be implemented in traditional school cultures. The core challenges for advocates of systems intelligence start with expecting adults to lead in an area that was all but totally neglected in their own education. This is one reason we advocate for increasing the voice of student leadership. It is also why field projects in the compassionate systems community focus so much on adults gaining practical experience with the tools and methods—often for several years before extensive work with students and within classes (Cook et al., 2021). Collectively creating trust, openness, and capacity to experiment and learn within an education community, be it a school, district or county, takes time and genuine commitment, and is fraught with many challenges.

Research can help here by deepening understanding of the educator skills and dispositions for effectively using systems learning tools like we have illustrated here and by studying what it takes to sustain complex cultural change processes over time in support of developing systems intelligence. There is opportunity to study longitudinal examples in a range of school settings and geographies like the examples of Dulwich College and Ventura County, California we highlighted above. Future studies could explore the organizational and community forces that make such practices difficult to sustain and case studies of strategies for dealing with those forces. We also see further study needed in how to support students and families in seeing "relational competencies" as a core element of their education—like learning from difficult conversations and interpersonal conflict, so that issues that typically become politicized and polarized are being held more respectfully and people develop ways to transcend finger pointing so as to inquire together into underlying systemic sources of problems.

As practical applications of the compassionate systems approach evolve, the concept of social fields also opens new paths to understanding authority and power structures. People in positions of authority, like a teacher in a classroom, inevitably have a disproportionate impact on the quality of a social field (Juul & Jensen, 2017). This can become an empowering way to understand positional leadership beyond coercive power—how we can use positional authority to foster trust, psychological safety, and the willingness to be vulnerable, as opposed to "driving my agenda" (Edmondson & Lei, 2014). Also, as practice with the approach develops, evidence builds that serious cultivation of contemplative practices matters. This includes but goes beyond introductory mindfulness for managing anxiety and stress, to regular practices that deepen awareness of self, other, and the quality of the social fields we co-create (Center for Systems Awareness, n.d.a.).

Cross cutting research

Last, stepping back from these three particular problem and opportunity areas of equity and access, youth leadership, and systems learning communities, there are basic questions around cultivating systems intelligence where better understanding can cut across all application areas, like:

- how young learners use systems thinking tools. Educators who have never introduced such tools into their classroom are often shocked by the ease and sophistication of children's work with stocks and flows and feedback loops;
- how systems thinking and systems sensing capacities complement one another in enabling other complex thinking capacities like problem solving and design thinking;
- how learners at all ages benefit from collaboration strategies like joint construction of simple system models to develop appreciation of one another's views of complex problems;
- practical pedagogical strategies for shaping learning spaces that balance emphasis on social (intra- and interpersonal) and technical competencies and sensitivity to the biases in inherited pedagogies regarding both;
- given our premise of the innateness of systems intelligence, we need to keep asking, "What happens in various developmental stages to this innate systems intelligence?" Specifically, what roles are played by basic developmental factors like ego formation and cultural factors like reinforcement of the isolated separate self in modern society?
- How might different mental models and artifacts of our education system enable or work against the cultivation of systems intelligence? For example, What role in discouraging systems intelligence is played by biases for conceptual knowledge favored over operational knowledge ("know about" versus "know-how"), reductionistic analysis, win-lose competition, depleted social fields, prioritizing decontextualized (i.e., general) versus situational understanding, and the simple lack of attention to systems intelligence?
- What does the development of systems intelligence look like in different cultural contexts? Cultivating systems intelligence presents an unusual challenge and opportunity in the ways a common set of ideas and practices are in use across ages, hierarchy, and roles. For example, the compassionate systems approach is growing today in diverse global settings and at multiple levels, from schools and districts to county, regional, and state and provincial scales, where it spans levels of hierarchy—from students and teachers to ministry leadership, including many involved in out-of-school education (Center for Systems Awareness, n.d.b.). This creates a unique opportunity to study learning and change at the scale of states and provinces.[5]

As the field of systems intelligence advances, we take inspiration from how the growth of SEL benefited from synergies between lab- and practice-oriented research. Although we have emphasized here the know-how of experienced education practitioners, it may well be that brain science studies of the neuro-physiological correlates of systems awareness can contribute to this whole field—much as have studies of amygdala dynamics and neuronal density ("grey matter") enriched understanding of emotional self-regulation and the role of mindfulness meditation, respectively (Guex et al., 2020; Maguire et al., 1999).

Connecting with ancient understandings of interdependence

Last, because this approach to systems intelligence embraces the relational as well as the conceptual aspects of systems, it connects with many traditions older than contemporary Western systems science, like Indigenous epistemological and ontological traditions (Andreotti, 2020; Cajete, 2015; Kimmerer, 2013; Yunkaporta, 2019). For example, although the term *generative social field* might be relatively new, the underlying idea aligns with why, for millennia, ritual has been so important to many cultures as a way to slow down and attend individually and collectively to the feeling of being together and to being with a larger presence that arises from our being together. Although nature herself provided the shared teacher and common language for Indigenous understanding of interdependence, might common tools like the Check-In protocol, the systems thinking iceberg, and ideas like generative social fields offer a bridge that connects the ancient and the contemporary? Today, this is one focus of new projects in places where tribal education traditions are reviving, like in British Columbia.

Conclusion

> The mark of every golden age is that the children are the most important members of society and teaching the most revered profession.
>
> —Traditional Chinese wisdom

For us as authors, organizing this review article has helped us draw together and acknowledge the work of extraordinary education innovators over many decades, work that is often not seen as connected. Hopefully, it can also inspire next generations of exploration. If cultivating systems intelligence is a shared birthright akin to cultivating artistic or mathematical intelligence, then it offers much to connect us across cultures and in common cause addressing our most pressing shared societal challenges—with climate change being one of the most urgent and serious of our time. Today, 8 billion humans are trying to live together on this small planet, which had only about 1.5 billion people at the start of the twentieth century. The consensus among scientists is that, at our current standards of population, economic activity, material consumption and waste, we use about 1.5 Earths.[6] As always happens, the consequences of environmental stress fall most heavily on the poor, a key factor driving the extraordinary movements of hundreds of millions of migrants, in turn creating political backlashes around the world.

At some point we will need to awaken and realize that the future of all societies is shaped by its system of education, and we denizens of modernity are no different. It is naïve to think that the problems of our modern world will shift without changes in the modern system of education that has shaped the humans, all of us, who have created these problems. Through early years learning, we can nurture systems intelligence starting with our youngest and cultivate this sense of ecological and societal interdependence throughout their development, leading to generational shifts in consumer behavior, design, governance, and policy making. We believe recognizing that we humans have a capacity to understand interdependence—and that we actually already know a great deal about how to develop it through education—may prove critical to our collective future.

CRediT authorship contribution statement

Peter M. Senge: Writing – review & editing, Writing – original draft, Conceptualization. **Lana Cook:** Writing – review & editing, Writing –

[5] At state or provincial scale in California, British Columbia, and across several hubs in Asia-Pacific (Singapore, Indonesia, Hong Kong, Japan, and Australia).

[6] For example, the Stockholm Resilience Centre (2023) estimates that six of the eight basic "planetary boundaries for human flourishing" have now been crossed.

original draft. **M. Jennifer Kitil:** Writing – review & editing, Writing – original draft. **Kimberly A. Schonert-Reichl:** Writing – review & editing, Writing – original draft. **Jean M. Clinton:** Writing – review & editing, Writing – original draft. **Mette Boell:** Writing – original draft, Conceptualization. **Jacob S. Martin:** Writing – review & editing, Writing – original draft, Resources. **Charlotte Ruddy:** Writing – review & editing, Writing – original draft, Resources.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This work was supported by the Carnegie Corporation of New York [G-CS-24-61221, 2024] as part of their core support of the MIT Systems Awareness Lab. The authors would like to thank Bahia El Oddi for her steadfast support in the project management of this effort. We also thank Trina Haygaru for her expertise and insight in systems intelligence in primary years education which deeply shaped our thinking. And finally, we thank Nicola Wilson and Alex Hall-Gray of Dulwich College (Singapore) for their support of this effort.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.sel.2025.100167.

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