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EDITED BY
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REVIEWED BY
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Emily Freeman,
The University of Newcastle, Australia

*CORRESPONDENCE
Angeline S. Lillard
lillard@virginia.edu

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Why the time is ripe for an education revolution

Angeline S. Lillard *

Department of Psychology, University of Virginia, Charlottesville, VA, United States

Most American classrooms employ a teacher-text-centered model of instruction that is misaligned with the developmental science of how children naturally learn. This article reviews that science and the origins of the common instructional model, including three modifications intended to make it work better (grades, age-graded classrooms, and high-stakes testing) yet which time has shown are problematic. Considering scientific theory change, I show how parallel circumstances exist between the situation in education today and pre-Copernican astronomy, building the case that education is now ripe for a paradigm shift in its instructional model, away from teacher-text-centered learning and to highly structured instructional environments that support self-construction through limited free choice. One proven model that responds to our world's contemporary needs is described, and a prescription is offered for how to bring about a paradigm shift in educational practice.

KEYWORDS

child development, constructivism, educational change, education history, education reform, paradigm shift, social justice

Introduction

The COVID-19 pandemic brought schooling into homes. In response to the instructional practices they then witnessed, 61% of parents opined that schools should rethink their methods of education (Hart and Snyder, 2020). The pandemic period also saw renewed attention to social inequities—a problem which we have long hoped the school system could repair, yet which it may actually exacerbate. Learning rate differences between world majority and white students grow larger during the school year and shrink in the summer, when children are not in school (Haberman, 2010; Kuhfeld et al., 2021). The predominant school model, teacher-text-centered (TTC) education (Dintersmith, 2018), does not comport with child psychology (Bjorklund, 2022; Overton, 2015; Darling-Hammond et al., 2019), which may be why schools have a long history of being considered inadequate (Dewey, 1923/2020; National Commission on Excellence in Education, 1983; Sarason, 1996; Cohen and Mehta, 2017; Moeller et al., 2020). The TTC model also encourages competition, group-think, and other ways of being that counter social justice education (Hackman, 2005) and culturally responsive pedagogy (Hammond, 2014; Nasir et al., 2021). And in light of new large language models like ChatGPT, education that relies on reporting back information is cut at the knees (van Dis et al., 2023). In this review and position article I consider how children learn, the source of the TTC model and reasons for its longevity, and alterations that have been made to try to make the TTC model work. Next I explain parallels between the situation for education today and Renaissance astronomy (Kuhn, 1957, 1962/1970), describe an education system that is aligned with child psychology and the contemporary imperative of social justice (Montessori), and suggest how we could come to adopt such a model on a wide scale.

How children learn

A child develops into an adult by constructing an elaborate representation of self and world, and learning to interact with and exercise agency in that world. This development occurs in a dynamical, non-linear fashion across childhood (Overton, 2015; Darling-Hammond et al., 2019; Nasir et al., 2021).

Outside of school contexts, with appropriate environmental support, children learn a great deal without didactic instruction; such informal learning is "embedded in meaningful activity; builds on the learner's initiative, interest, or choice. . . and does not involve assessment external to the activity" (Rogoff et al., 2016, p. 358). In essence, supported by the material and social environments, children can teach themselves. Infants are not told how to form syllables or walk on two legs; given exposure to others who talk and walk, they figure it out. For example, from 4 to 8 months infants begin to focus their attention on talking people's mouths, gleaning the information they need to form phonemes and eventually speak (Lewkowicz and Hansen-Tift, 2012). Slightly older children find available supports to pull themselves up and practice balancing on two legs until they can walk. Infants direct their attention to stimuli of developmentally-appropriate levels of complexity (Kidd et al., 2012, 2014), causing their sensory systems to develop (Merzenich, 2001). Children seek challenges and struggle to overcome them, focusing on what is slightly more difficult than what they can do easily—at the edges of their "zones of proximal development" (Harter, 1978; Vygotsky, 1978; Danner and Lonky, 1981; Gerken et al., 2011; Téglás and Bonatti, 2016; Cubit et al., 2021). Absent external interference, in natural contexts, children seem to have inner guides directing them to the right level of challenge to develop themselves and to learn (Montessori, 1967/1995; McCall et al., 1977; Gerken et al., 2011).

As such, children's natural development is aligned with principles of constructivism (Dewey, 1923/2020; Brooks and Brooks, 2001). Child-centered constructivism is taught in schools of education (Woolfolk et al., 2015), but (contrary to some claims) it is rarely well-implemented in schools for children (Dintersmith, 2018). I believe this is both because constructivist education lacks structural support in the schools we have–these schools were designed for TTC education–and because most teachers have deeply-held TTC school schemas left over from their own childhood school experiences (see also Buehl and Beck, 2015). Therefore, despite what was embraced in their teacher education courses, and even if they retain child-centered constructivist beliefs, new teachers quickly conform to the TTC model in their teaching (Renninger, 1998; Cook et al., 2002; Greene et al., 2008; Savasci and Berlin, 2012; Buehl and Beck, 2015; Carroll and Lillard, 2022). Even in observations of kindergartens today (Bassok et al., 2016; Engel et al., 2021), the TTC model is the predominant form of teaching. In keeping with Dintersmith's (2018) recent first-hand observations of hundreds of classrooms across the US, the vast majority of the roughly 400 university students I teach annually tell me they experienced the TTC model most of the time from kindergarten through grade 12. Taking an analogy from dynamical systems, the TTC model is an "attractor state"—a state toward which systems natural gravitate (Dudkowski et al., 2016)—in the context of school classrooms. Teaching in conventional schools naturally gravitates toward didactic lessons, textbooks, boards, grades, and tests, all led by a teacher who is often seen standing in front of a class of same-aged children, who do the same activities as their classmates most of the time. Next I consider the origins and development of this model.

Abbreviations: TTC, Teacher-text-centered model of education; CEI, Child-environment-interaction model of education.

The teacher-text-centered school model

The Western model of formal schooling originated centuries ago in monasteries to fill ranks in the churches (Tyack, 1974), and later to ensure everyone could read the Bible by deciphering the alphabet. Pupils read texts and then recited them; memorization of texts constituted learning. Teachers assigned reading and judged the recitations, the evidence of memorization. Schooling's purpose later expanded to also include numbers. By the time industrialization and consequent urbanization brought about mass public education in the 1800s, school (typically a one-room, multi-age classroom) was well-understood to be where one learned the "three Rs"—reading, writing, and arithmetic (Tyack, 1974). Many teachers were needed, and a model of schooling began to take shape.

Teachers were and continue to be at the center of this model. This makes sense, I speculate, for three reasons. First, teachers are knowledgeable, so it stands to reason that to educate, teachers should tell children what they know. Testimony is a primary means of educating; it matches our commonsense view of learning, since as adults, we seem to learn (in a linear fashion) what we are told or read (Harris, 2012). Children are born relatively incompetent, seemingly knowing nothing. To counter this ignorance, teachers deliver information to children. Second, adults like to do things, including actions they perceive as being to and for children. A teacher at the center of a learning environment feels agency (Tapal et al., 2017), and feels he or she is helping children by telling them things. Third, British empiricism, reflected in John Locke's description of the child as a tabula rasa, or blank slate on which to write, was dominant as mass schooling began. As one intellectual heir to this tradition famously claimed, any child could be made into any type of adult by how the child was taught (Watson, 1913). Pulling these three reasons together, in the TTC model, teachers change children by providing conditions (talk, texts, tests, grades) that cause children to learn the information they are told.

The TTC model became entrenched in the United States from 1850 to 1930 because of the confluence of cultural ideology and social changes occurring at the time: industrialization, urbanization, and immigration (Tyack, 1974; Vinovskis, 2019). Civic leaders with deep respect for standardization created bureaucracies to educate children of immigrants who were congregating in new cities (Callahan, 1962). They were experts at scaling, and they scaled the educational methods that were then in vogue very well–so well, in fact, that the TTC model still dominates today. Yet the TTC model has always had problems because it comports poorly with natural laws of development (Bjorklund, 2022; Darling-Hammond et al., 2019). Constructivism is a better match to those laws, which is why it is taught in schools of education. Yet constructivism has

failed to take hold in the schools (Dintersmith, 2018), because, as noted, it lacks supporting structures there; therefore, new teachers quickly revert to the TTC model (Renninger, 1998; Cook et al., 2002; Carroll and Lillard, 2022), which continues to be problematic for child development. Consistent with this, a recent study found that although teachers in conventional teacher training programs find student-centered beliefs more favorable than teacher-centered ones, experienced conventional teachers are more apt to endorse teacher-centered beliefs (Carroll and Lillard, 2022). And yet the TTC model brings with it many problems; efforts to address its problems have resulted in other problems, like a whack-a-mole game at a carnival. The next section discusses three major adjustments or addenda made to fix the TTC model and ensuing problems.

Major addenda: tinkering with the TTC model

At least three major addenda have been instituted in attempt to fix problems that arise with the TTC model. Although "major", the revisions have thus far not been *revolutionary* in the sense of a scientific revolution or paradigm shift—for example, they have not involved new ontologies or disrupted causal-explanatory frameworks (Kuhn, 1962/1970). The revisions operate under and are incorporated into the basic TTC conceptual scheme. Because the revisions thus far have retained the old TTC paradigm, Tyack and Cuban (1995) argued that school revision can only involve *Tinkering Toward Utopia*—creating adaptations or addenda aimed at improving the existing system, but not fundamental restructuring (Hattie and Yates, 2013). I challenge that position, in arguing that conditions are ripe for a paradigm shift. First, I examine how attempts to repair the TTC model have led to new problems.

Three problems with the TTC model are that it can reduce motivation to learn, that it presumes more similarity among children than actually exists, and that large numbers of children fail to learn well in it. The three major addenda introduced to deal with these problems are (1) extrinsic motivators to get children to apply effort to learning in school, (2) age-graded classrooms and tracking to reduce student variability, and (3) high-stakes testing to ensure that "no child [is] left behind." Each addendum has failed to truly solve the problem it was designed to solve, and each also has had unintended negative consequences for children that became more obvious in the contemporary context of COVID-19 and tensions around social justice.

Instilling motivation with extrinsic motivators

The TTC model assumes that if a teacher (or text) delivers information, children will learn it. A long-recognized problem with this assumption is that learning requires motivation (Simon, 2001). Learners decide what to attend to; attention is a precondition for learning (James, 1890; Merzenich, 2001), and learners are therefore fundamentally responsible for their own education (Posner and Rothbart, 2007). But learning in the TTC model is often not inherently motivated because a teacher and/or preset curriculum determines what children should learn each day, and children might not be interested. In the early 1700s, Cambridge University's response to students not being motivated to learn math was to institute competitive ranking for its first degree, the Mathematical Tripos (Schneider and Hutt, 2014). The Tripos was like an individual sports tournament, and the highest scorer was awarded a portion of the university's endowment for life. The Tripos exam was thus instituted to motivate students to learn math, with the promise of a generous monetary prize for the winner. In other schools as well, extrinsic motivators—punishments and rewards—were instituted to inspire children to put effort into learning. Hitting children who did not learn or even behave in a manner conducive to learning was common in the 1800s (Tyack, 1974). The A to F grading scheme gained traction in the United States as an extrinsic motivator in the early 1900s and is still prevalent today (Schneider and Hutt, 2014); other countries use different schemes, like 1–10 in Germany. Spelling bees, class rankings, "read for pizza" schemes, demerits, detentions, and suspensions also address the motivation problem inherent in TTC education. Such extrinsic motivators were added to make a poor model work better.

Although they made the TTC model serviceable for many children, extrinsic rewards do not work for everyone; children with attention differences, for example, suffer in terms of both motivation and performance in TTC schools (Gut et al., 2012). Grades are also anathema to culturally relevant (Ladson-Billings, 1995) or culturally responsive (Hammond, 2014) teaching, which are aimed at social justice. Such teaching has many features, one of which is using formative assessment that is instructive, not evaluative. By their very nature grades are evaluative, whereas comments and feedback are instructive. Furthermore, use of extrinsic motivators to get children to learn and behave in school has unintended negative consequences. For one, to varying degrees, for many students extrinsic motivators supplant learning as the main purpose of school; students tune out when they hear "it won't be on the test." During COVID-19 grades were not given in many districts, and parents complained that this eviscerated all their children's motivation to learn in school. This was unsurprising: A solid body of research has demonstrated that when one was initially intrinsically motivated to do something, then rewarded for doing it, and then the rewards are removed, one subsequently will find that the intrinsic motivation has evaporated (Deci et al., 2001). In TTC schools, children's intrinsic motivation to learn in school declines each year (Corpus and Wormington, 2014), perhaps because exposure to poor grades (low rewards) increases.

In sum, the first addendum to fix the TTC model was grades, which the model needs to motivate learning, and yet grades: are in opposition to the principles of culturally relevant education, stigmatize children with learning differences, and have perverse effects on motivation because they supplant real learning with good grades as students' goal in school.

Minimizing differences with age-graded classrooms and tracking

A second addendum to the TTC model concerns classroom composition. The TTC model presupposes that all children are

the same, such that the teacher can deliver information to a group and virtually all the children will learn it. This supposition fails to acknowledge difference, which is another reason the TTC model fails to provide culturally responsive education; a culturally responsive pedagogy acknowledges children's different opportunities and resulting needs (Hackman, 2005; Hammond, 2014). Yet the notion of standard materials (less educated children) from which to create new and improved products (more educated children) is a principle of the efficient factories that the creators of the American school bureaucracy admired (Callahan, 1962; Tyack, 1974). By contrast, America's one-room schoolhouses grouped all children together, regardless of age and ability; small groups recited information to the teacher or assistant while others worked at their desks (Angus et al., 1988). Graded classrooms were first instituted in America in 1852, in Boston, with the purpose of improving efficiency: Teachers could specialize in information geared at a particular level of learner. Initially graded classrooms bore no set relation to child age—a 10-year-old would be in the same grade as a 6-year-old if both were just learning to read—but across the early 1900s age-grading became the dominant instantiation (Tyack, 1974; Nelson, 2002). This is the second major addendum to the TTC model: Children of the same age are grouped in a single classroom, with the idea that they will be at the same level, hence can be taught the same information in the same way to change them into more educated beings.

However, the problem of differences in a model designed for sameness did not end with age-graded classrooms. Some 6-year-olds learn quickly, and others learn more slowly. Thus, grouping by ability within a grade (a type of "tracking") also occurred, spreading through schools into the 1920s (Tyack, 1974). This practice periodically recedes under charges that it is undemocratic and unfair (Loveless, 1999), but then re-emerges because children do differ, for example in prior opportunities, interests, and the speeds at which they learn (Steenbergen-Hu et al., 2016). The vast majority of students experience ability grouping today (Loveless, 2013).

Even with ability grouping, some children lag so far behind that they are retained in the same grade the following year. These are all efforts to homogenize—to make the children in each classroom as similar as possible, so that the teacher can deliver information in the same way, at the same pace, all at once, to all the children. Because modern inclusion values have led to placing children with autism, dyslexia, ADHD, beginning English, and other learning differences in a single classroom, teaching in the TTC model today can be very challenging; the 2008 MetLife survey found almost half of teachers report that their students so heterogeneous that they cannot teach them effectively (Markow and Cooper, 2008). The teacher shortage is increasing amongst these challenges (Duncan, 2022). More recent innovations to address the fact that children's uniqueness is problematic for the TTC model are "differentiated classrooms" (Tomlinson, 2014) and teaching strategies based on Gardner's (2008) theory of multiple intelligences. These extensions to the TTC model were added in effort to make it work, when the fundamental problem lies in model's need for homogeneity. Culturally responsive and scientifically based pedagogy both call for individualizing education (Hammond, 2014; Darling-Hammond et al., 2019; Nasir et al., 2021), making this second addendum to try to fix the TTC model–graded classrooms and ability grouping–another way the TTC model is out of step with the times.

High-stakes testing to save those left behind

The third major addendum to the TCC model is much more recent. While *A Nation at Risk* (National Commission on Excellence in Education, 1983) raised concerns about the quality of American education, data from the NAEP (National Assessment of Education Progress) tests beginning in 1969 made clear that many children, particularly those at the intersection of poor, southern, and Black, were not learning at par, which was thought to be responsible for the relatively poor economic health of the southeast region of the country (Vinovskis, 2019). The first President Bush and 49 governors met in Charlottesville, Virginia in 1989 and agreed on a set of education goals that paved the way for the second President Bush's No Child Left Behind Act in 2002, making federal funds contingent on "high-stakes tests" that children take annually in Math and English Language Arts from grades 3 though 8. When children's scores did not increase every year, schools were closed and teachers fired. The subsequent Every Student Succeeds Act (ESSA) retained the tests, but gave states more control. These laws presuppose that children fail to learn because teachers are not trying hard enough, and/or because schools keep incompetent teachers. This supposition comes directly from the TTC model, since it holds that the children are raw materials that can be changed by the teacher. Under these laws, schools and teachers are rewarded or punished based on children's test performance (Jones, 2007). Initially, the testing policies seemed to work, in that scores did increase on the NAEP from 2001 to 2009. For the subsequent decade, scores remained flat (Ferguson, 2020; Matheny et al., 2023).

In addition to not achieving their goal of yearly improvement, the tests have had unintended negative consequences (Jones, 2007; Zhao, 2017). They have reinforced and even increased the use of dehumanizing factory-style Taylor management principles first applied to schools in the early 1900s (Au, 2011), when children were explicitly referred to as raw materials and teachers as mid-level managers (Bobbitt, 1913, as cited in Callahan, 1962, pp. 89–90). Worst hit are lower income schools, which have doubled down on what has been called the Pedagogy of Poverty—top-down, teacher-directed, didactic instruction that is increasingly limited to the subjects and discrete knowledge bits being tested (Greene et al., 2008; Haberman, 2010). Further, the tests exacerbate the inequality they were intended to reduce (Zhao, 2016), increasing drop-out among the poorest students (Darling-Hammond, 2007; Au, 2013). The tests lead to decreased time spent on all non-tested material (Ladd, 2017). They reduce education to filling out bubble sheets. They have reduced student engagement (Markowitz, 2018), and they have increased stress in schools. Students ages 7–15 show cortisol levels that are 15% higher in the period preceding a high-stakes test; the rise is particularly marked in low-income schools (Heissel et al., 2021). Children whose cortisol levels fluctuate the most (in either direction) also perform the least well on the tests, and relatively less well than one would expect based on their grades. Furthermore, as noted, teachers are leaving the profession in high

numbers, in part due to the dissatisfaction created by the testing regime (Sutcher et al., 2016). Thus, the tests have not served their purpose, have many negative consequences, *and* cost billions of dollars to implement (Vinovskis, 2019).

Summary

These three major addenda (grades, age-graded classrooms/tracking, and high-stakes tests) are all patches intended to make the TTC model work serviceably well for educating all children, helping them develop intellectually from immature to adult state. But the addenda have not solved the fundamental problem, which is the educational model we employ in schools not comporting well with how children naturally learn. This situation in education parallels that of astronomy in the late Middle Ages.

The analogy to Kuhn's revolutionary theory of revolutions

Kuhn's (1962/1970) *The Structure of Scientific Revolutions* was for many years the most cited academic work in all of the social sciences and humanities (Kaiser, 2012). Before Kuhn's (1962/1970) book, accepted doctrine was that science is incremental–new discoveries gradually build atop old ones, similar to the "tinkering" in schools described by Tyack and Cuban (1995). But Kuhn noted that the process is on occasion actually seismic, in that there are moments in science when accepted paradigms are overthrown in favor of new ones. He called these "paradigm shifts," meaning changes in the set of laws, theory, application, and instrumentation that provide models from which coherent traditions emerge (Kuhn, 1962/1970). One of his classic examples is the dramatic change in the European conceptualization of the universe that occurred in the 1500s.

Paradigm shifts

Since antiquity, the prevalent model of the universe was a two-sphere one, in which the earth sphere was stationary and occupied the central position, and the heavens, dotted with the stars and rotating, was the outer sphere (Kuhn, 1957). A set of "wanderers," including our moon, Mercury, Venus, our sun, Mars, Jupiter, and Saturn, orbited at different rates through the zone between these two spheres. A major problem of astronomy was explaining the orbits of these objects, which was crucial for calendars and Astrology, an important "science" of the era. Like the TTC model for learning, the two-sphere model aligns with common sense. It certainly seems like Earth is stationary, and like the sun, moon, planets, and stars are moving around it, just as it seems like children learn well from being told.

However, the two-sphere model is fundamentally misaligned with reality, and so predictions from it were wrong. As with TTC education, edits to the model were needed to make the model work serviceably well. Over the years, many new entities like *deferents* and *eccentrics* and *epicycles* were invented and incorporated to the conceptual model to address inconsistencies like why planets sometimes appeared to change direction, vary in brightness in different seasons, and appear in locations other than what the model predicted. Eventually a conflux of intrinsic and extrinsic conditions led to the collapse of the Ptolemaic model. As will be shown, the conditions that preceded that collapse also exist today.

Three intrinsic reasons for the demise of Ptolemaic astronomy

Like the TTC model of schooling, Ptolemaic astronomy was serviceable; using a model of the universe that put Earth at the center, astronomers were able to predict the paths and locations of stars and planets with serviceable accuracy. But as optics improved, and inaccuracies accumulated, the model became increasingly complex, straining under the weight of addenda intended to fix it. And yet despite the addenda, predictions from the model were still inaccurate, and the model ceased to seem serviceable. Thus, two inherent conditions for a scientific revolution existed by the early 1500s (Kuhn, 1957, p. 76): accumulating data showed the model did not work, and attempted repairs had rendered the model excessively complex, yet still erroneous. Similarly, in the realm of education, poor test results, increasing score gaps, and low student motivation suggest the TTC model is not working, despite the bureaucratic complexity devoted to model repair.

A third intrinsic condition for a paradigm shift was also present by the 1500s: An alternate, superior model was being floated among astronomers, ready to take Ptolemaic astronomy's place. This superior model was the heliocentric view, with the sun at the center. The ancient Greek Heraclites had long ago theorized that the earth moves, but influential people like Aristotle and later Ptolemy argued that this stance defied common sense. Further, the heliocentric view defied Renaissance Europeans' conceptualization of the universe and their place in it (The Great Chain of Being and the specialness of humans to God, Aristotle's theories of motion, and so on). For these reasons, Heraclites' idea was not immediately accepted when Copernicus and others revived it in the 1500s.This is often the case for radical changes of paradigm (Kuhn, 1962/1970): the establishment has much at stake in the presiding model, and does not readily abandon it. Yet the presence of an alternative model is a precondition for a paradigm shift. These three intrinsic conditions (accumulating inaccuracies; excessive complexity; and an alternate, superior model ready for adoption) exist for the TTC model today.

Three intrinsic reasons for a paradigm shift in schooling

First, like the ancient astronomers, educators have continued to try to repair the TTC model. For example, a school system might add the Common Core or eliminate grades for younger children. Schools institute and then abandon tracking and inclusive classrooms. Under ESSA, states are trying new forms of assessment. In this case teachers are burdened by the weight of complexities created by reforms intended to fix the TTC model, resulting in "fragmentation, overload, and incoherence" (Hattie and Yates, 2013, p. 2); they suffer from "reform exhaustion" as they are constantly asked to implement new programs to solve problems arising from the TTC model and its addenda (Sarason,

1996; Dworkin, 2001). Second, we are faced with accumulating inaccuracies, because TTC is a fundamentally flawed model for children's development. We teach according to the model, but contrary to its predictions, children are unalike, are often unmotivated, and too often do poorly on standardized tests.

> We have inherited an education system designed in the early [1900s… This system's] espoused curriculum and teaching norms were based on prevailing scientific assumptions concerning the nature of knowledge, the learning process, and differential aptitude for learning. Although they have been profoundly challenged by the past three decades of research in cognitive science and related disciplines, the assumptions of the 1920s are firmly ensconced in the standard operating procedures of today's schools.
>
> (Resnick and Hall, 1998, p. 90–1)

The situation has not notably evolved in the quarter century since Resnick and Hall wrote those words. "Preparing all students to meet higher academic standards will require instruction that is different and much better than the instruction most of the nation's students receive today" (Duncan and Murnane, 2014, p. 141). "Changes are needed within our education system, since our current system was not designed with [what we now know about human development] in mind" (Darling-Hammond et al., 2019, p. 3).

In addition to the addenda having made the system more complex, and new data making clear that TTC does not correspond with how children learn and develop, education also has an alternative model in the wings, which will be described more later: a school model that implements *well-scaffolded* child-centered constructivism, namely Montessori. First, I consider how existing extrinsic circumstances also preceded astronomy's paradigm shift, and the parallels that exist for education today.

Extrinsic reasons for paradigm demise

Four extrinsic circumstances that precipitated the demise of Ptolemaic astronomy exist today. First, the period leading to the Renaissance was a time of tremendous social upheaval, and such times provide fertile ground for radical paradigm shifts (Kuhn, 1957). The social structure of feudal lords and the Church that had reigned through the Dark and Middle Ages was giving way to a new mercantile class (e.g., the de Medicis). Even before COVID-19, the forces of globalization, change from a material to a service/knowledge economy, and advances in technology have contributed to a time of tremendous social upheaval. COVID-19 exacerbated this upheaval, as parents struggled to school from home, and as already dire income and racial opportunity gaps were reinforced by the pandemic (Dorn et al., 2020). Added to this are the repeated and highly publicized incidents of police violence and racism, and increasing gun violence across the nation; we are a country in turmoil, and turmoil can precede tremendous change.

The other three extrinsic factors are intertwined, so will be discussed in a piece, first for astronomy, and then for education. Related to social upheaval, the Renaissance brought in a new intellectual climate, in this case a renewed appreciation of precision; the fact that mathematical predictions from Ptolemaic astronomy were not working was particularly troubling in this broader intellectual climate. As organizational social units enlarged, the need for accurate calendars increased, and the accumulating errors of the Julian calendar became more troubling. "Reform in the calendar […] demanded reform in astronomy" (Kuhn, 1957, p. 126). Related to this, and third, was economic necessity, tied to an increase in seafaring which required more accurate models so that ships venturing long distances across oceans could reliably navigate by heavenly bodies. And fourth, in addition to being the leading astronomer, Ptolemy was also the most famous geographer in ancient times; as increased seafaring revealed that his geography had serious mistakes—for example, no "torrid zone" too hot for human survival was found as Europeans ventured south (Hansen, 2020)—his credibility declined, raising doubt about his model of the universe as well.

Moving to education, social changes have led to widespread acknowledgment that the TTC model does not naturally foster the skills children now need. Cultivating "21st Century Skills" is considered an economic necessity yet TTC schools fail to develop them (Knudsen et al., 2006; Golinkoff and Hirsh-Pasek, 2016). The intellectual climate increasingly embraces complex and dynamical systems, from quantum physics to bio-social-ecological developmental theories (Overton, 2015). Advances in computing technology support complex approaches as masses of data can be computed in milliseconds. Education is today recognized to be a complex rather than a linear system (Jacobson et al., 2019), and yet the TTC model is linear. Finally, major architects of the TTC model are viewed less favorably today (Berliner, 1993), shedding doubt on the prior model. For example behaviorism has been supplanted by cognitive science, and features valued by humanists and not by behaviorists (emotionally warm relationships, for example) are recognized as key to student learning (Cash et al., 2019). Despite decades-long efforts to eradicate school racism under the TTC model, it persists (Johnson and Pak, 2019).

Summary

These four extrinsic cultural conditions (social upheaval, a new intellectual climate, economic necessity, and doubt in the prior model) combined with the three intrinsic ones (accumulating data showing it does not work, increasing complexity introduced in attempt to repair it, and a new paradigm ready to replace the old one) to support a paradigm shift in astronomy in the 1500s; the same conditions exist and could support a paradigm shift in education today. When enough data accumulate that cannot be assimilated to an existing model (despite concerted efforts to fix it), the data appear to better fit a different model, and the social conditions are suitable, a revolution in thought finally occurs—but rarely without resistance.

Resistance: TTC as the attractor state

There is always resistance to paradigm shifts. An established paradigm has many stakeholders; the TTC school model is no exception. New models require a change in ontologies and causal-explanatory structures (Kuhn, 1962/1970), and such changes are

not easy. As noted, the TTC model in some ways makes intuitive sense, since we do learn through testimony, through being told things. We are attracted to agency, and the TTC model puts teachers in a position of doing things to children, transforming them into more educated beings. And people are used to the TTC model: It is the model most adults grew up with, so it feels right and natural, especially for those for whom it worked serviceably well. And it has worked serviceably well for many—had it not, it would not have survived this long. But as noted in the Introduction, there are many for whom it does not work well, and there are also reasons to believe that for humanity in general, a different model would work much better.

A possible shift in the dominant education model is helped by the fact that schools of education teach principles that cohere with constructivism already, although education scholars aim to embed those concepts in the TTC model (Cohen et al., 2002), where they do not easily fit. As noted, when budding young teachers assume their own classrooms, they quickly revert to TTC education (Renninger, 1998; Mintrop, 2001; Cook et al., 2002), even when they espouse child-centered, constructivist beliefs (Savasci and Berlin, 2012). Those beliefs quickly become more teacher-centered once teachers enter the realities of the TTC-school classroom (Carroll and Lillard, 2022). Conventional school operations are constituted of TTC elements like grades (the motivators), whole-class teaching (requiring sameness), and high-stakes tests (to make teachers make low performers do better on those tests). Without these elements, the TTC model works even less well; with them, and the bells, blackboards, textbooks, and so on, TTC becomes an "attractor state"—the state to which the system naturally returns. Lecturing, testing, and grading are emergent properties in the TTC system.

A second reason why many teachers revert to the TTC model is that they lack the necessary structural support to implement something better; valuing constructivist principles is insufficient.

Constructivism

Froebel, Pestalozzi, and Rousseau were 18th century proponents of constructivist, child-centered pedagogy (Fallace, 2015), and there have been waves of their "progressive" ideas gaining traction in schools ever since (Cohen and Mehta, 2017). As John Dewey observed, "education is not an affair of "telling" and being told, but an active and constructive process" (Dewey, 1923/2020, p. 26). Or as Montessori put it,

> We discovered that education is not something which the teacher does, but that it is a natural process which develops spontaneously in the human being. It is not acquired by listening to words, but by virtue of experiences in which the child acts on his environment. The teacher's task is not to talk, but to prepare and arrange a series of motives for cultural activity in a special environment made for the child. (Montessori, 1967/1995, p. 8)

Constructivism is well-aligned with culturally-relevant pedagogy as well, with their mutual emphasis on starting where the child is, respecting children as critical thinkers, and promoting a supportive and collaborative community (Ladson-Billings, 1995; Hackman, 2005; Hammond, 2014). Table 1 includes eight features of constructivist pedagogy and contrasts them with the traditional TTC model (Brooks and Brooks, 2001).

TABLE 1 Basic principles of constructivist vs. traditional pedagogy (Brooks and Brooks, 2001).

Constructivist	Teacher-text-centered
Curriculum presented whole to parts	Curriculum presented parts to whole
Student questions drive learning	Prescribed curriculum
Manipulatives and primary sources	Textbooks and workbooks
Students are thinkers, developing theories	Students are blank slates
Interactive teachers curate environment	Teachers disseminate information
Build lessons on student understanding	Test for knowledge retention
Continuous assessment through observations and projects; immediate feedback direct from learning apparatus	Assessment is separate from teaching
Collaborative student work	Typically work alone

There are wonderful descriptions of classrooms in which teachers do manage to apply constructivist principles within otherwise-TTC schools (Dintersmith, 2018; Darling-Hammond et al., 2019); such principles are well-supported by research. For example, among the principles of constructivism are that people learn best when they are interested in what they are learning, when they are active, and when they can make choices and feel self-determination (Levin et al., 1990; Renninger et al., 1992; Deci and Ryan, 2011). Well-designed manipulatives and embodied experiences result in the best learning outcomes (Macrine and Fugate, 2022), and collaborative learning is very effective (Nokes-Malach et al., 2015; Lillard, 2017). Assessment and feedback at the point of need are most useful, especially when they preserve intrinsic motivation, rather motivate the intrinsically-motivated learner with a grade or gold star (Deci et al., 2001). And children learn best when they can keep the big picture in mind, generating questions that keep curiosity alive (Jirout and Klahr, 2012). It is difficult to do this in TTC schools, but some very talented teachers do manage to. One challenge they face is that constructivist models have strong detractors who instead espouse TTC models under the term *direct instruction* (Kirschner et al., 2006). Indeed, when it comes to the kinds of learning assessed on high-stakes tests, constructivism fares less well than the TTC model (Mayer, 2004; Alfieri et al., 2010; Stockard et al., 2018); this contributes to the TTC model's traction, and its remaining an attractor state; this is why I advocate instead for a Child-Environment Interplay or CEI model.

Constructivist models are underspecified

Although there are talented teachers who manage, constructivism is rarely well-implemented because its most prominent proponents, like Dewey, gave principles and not specifics (Dewey, 1923/2020; Renninger, 1998; Cook et al., 2002). Unlike learning to walk or talk, school learning is not an evolved

capacity, and thus adults must structure the environment, for example by providing special equipment to guide and ensure children's learning. Without the backing of a solid constructivist pedagogy, teachers are asked to invent much of this equipment, and few teachers have both the talent and the time do this well. Ideally, a constructivist model would structure the environment across learning domains and from birth to university, so children would meet graduated yet consistent and coherent environments for learning as they advanced through school. Teachers would not be asked to invent the learning environment all anew.

Children need to grow with constructivism

In order for children to make positive choices in a constructivist framework with a minimum of teacher involvement, they need strong self-regulation and an active approach to their own education. TTC model teachers must regulate children's behavior because TTC circumstances are not well-fitted to children; hence, behavior management is heavily emphasized for TTC teachers in training (Emmer and Stough, 2001). As many former schoolchildren can recall, when TTC teachers exit the classroom even for just a few minutes, children often misbehave. Likewise, when older TTC-educated children are placed in constructivist classrooms, they may lack the necessary self-regulatory skills, leading teachers to revert to the TTC model and its regulatory techniques (like extrinsic rewards). In addition, the TTC model has the teacher or other authorities choose what children learn. The result is that students often become passive, and that passivity can persist even when older students are placed in constructivist classrooms. Because constructivist classrooms rely on active learners, they fail when students have already learned to adopt a passive stance to their own educations. An alternative model must start from preschool, raising children in the constructivist expectations of making useful independent choices, asking questions and pursuing answers, and engaging with the community.

Interim summary

Three major efforts to repair the TTC model have not fixed it, and have had undesirable unintended consequences. The situation parallels that of astronomy, when intrinsic and extrinsic factors precipitated a paradigm shift in a widely-accepted underlying model. The commonly-posed alternative to the TTC model is constructivism, and it is taught in schools of education, but it is rarely well-implemented in schools. Two reasons constructivism fails are that it is underspecified (leaving too much to the teacher), and it expects too much of children who have been conditioned by their experiences in TTC models. In response, teachers revert to the TTC model, which is an attractor state.

A successful alternative model

There is a middle path between TTC and discovery-learning-type constructivist models, herein called a child-environment-interplay model (CEI). CEI models give teachers the tools to implement constructivism well. Those tools include a coherent model, a well-structured set of materials, lessons, worked examples, and entrained teaching skills. CEI models also give children an evolving scaffold toward full independence in their learning, granting freedom within structure. Montessori is a prime example of a CEI model and will be discussed here; Waldorf is another CEI model. Cohen and Mehta (2017) discussed both as "successful niche reforms" because they have survived for more or less a century while other alternative approaches have arisen then virtually disappeared. Waldorf is only about 10% as common as Montessori (Debs et al., 2022), perhaps reflecting narrower appeal, but both have strong adherents. In many ways these approaches dovetail with culturally responsive teaching (Hackman, 2005; Hammond, 2014; Brunold-Conesa, 2019) and the science of learning and development (Darling-Hammond et al., 2019). "Guided play" or playful learning (Fisher et al., 2011) approaches also involve essential CEI elements of freedom within structure. In any domain, the number possible conceptual schemes is infinite (Kuhn, 1957); one must find the best fit for a given context. Compared to Montessori, other CEI models tend to be more teacher (thus, resource)-intensive and teacher-led, and therefore less embracing of children's independence and autonomy. Another important distinction is that Montessori was developed empirically through objective observation of children who were free to move about, rather than in an armchair, far from children. The freedom of the children was thought to be essential to understanding them; trying to understand children by watching them in TTC model environments, Maria Montessori claimed, was like trying to understand butterflies when only viewing them mounted on pins, rather than in their natural environments (Montessori, 1964). The system was gradually developed through trial and error over the course of a half century of intensive study of children.

Montessori

Although often thought of as a private preschool model, Montessori education extends across all the school years, is implemented in hundreds of public US schools (Montessori Census, 2020; Hilty et al., 2021), and is rapidly expanding worldwide, with over 15,000 schools (conservatively estimated) in at least 75% of the world's countries (Debs et al., 2022). Over half of the children in US public Montessori schools are children of color, and in the US public Montessori schools are more diverse than public schools generally (Debs, 2016). Montessori is sometimes dismissed based on misunderstanding or bad examples, which abound because "Montessori" is not trademarked (Lillard, 2019). The description of Montessori here reflects the approach described in Dr. Montessori's books (e.g., Montessori, 2017a) and taught by the organization she founded, the Association Montessori Internationale (AMI). While outcomes from schools that adhere well to the AMI program (including AMI-trained teachers, specific 3-year age groupings, long work periods, full sets of materials, and relatively large classes with high child:teacher ratios) are strong (Lillard and Else-Quest, 2006; Lillard, 2017; Denervaud et al., 2019, 2020a; Guerrero et al., 2023), other implementations are in need of more rigorous study. Even despite the range of variation in how Montessori is implemented, two new and separate meta-analyses of Montessori, one originating in the United States and the other

in France, both reported positive effects on both academic and nonacademic outcomes (Demangeon et al., 2023; Randolph et al., 2023). In the next section the structure of Montessori education is described, followed by an explanation of how the pedagogy is constructivist, child-centered, and compatible with culturally responsive pedagogy. The article ends by noting how all CEI models address the main problems of the TTC model, and suggests how a paradigm shift in our school model could come about.

Strong, coherent structure

Montessori is a child-centered constructivist education within a highly structured framework. Over 50 years, beginning with a small set of materials that Itard (who educated "the Wild Boy of Aveyron") and his student Seguin had used with intellectually disabled children (Montessori, 1967), physician Maria Montessori and her collaborators developed a theoretically coherent alternative approach to education, with a structured apparatus comprised of hundreds of hands-on materials and lessons for children from birth to 12; her ideas for ages 12–18 have been carried out by successors (Lillard, 2017). The Montessori materials and lessons are interconnected across subjects and levels, and arranged methodically in classrooms. Learning occurs because of the interplay between child and the resulting environments, guided by an observant, loving, and well-prepared teacher (Lillard and McHugh, 2019a). AMI teacher training requires 9 months, and is led by trainers who themselves had many years of education, experience, and apprenticeship before becoming certified to train; the training is consistent across an international network of training centers (Lillard and McHugh, 2019b). Teachers are supported by regular conferences, expert consultations, and Montessori-trained heads of schools. Through this training and support, AMI-trained Montessori teachers have a strong and consistent theoretical and physical structure within which to implement constructivism (Cossentino, 2009). Montessori teacher training, properly done, is claimed to change the teacher's philosophy not just of the child, but of all of life.

Constructivist

Montessori adheres to constructivist principles as presented in Table 1 (Pottish-Lewis, 2021). The curriculum is presented whole to parts, and student questions drive learning. For example, the curriculum for ages 6–12 centers around five Great Lessons offered each year: the origins of the universe, life on earth, human beings, written language, and number. These and lessons on manners are the only whole-class lessons offered in all of Montessori before junior high school (age 13). In all lessons, teachers are charged to inspire students to ask questions about aspects of the lesson, and by age 6 to then research and write reports (often in small self-formed groups) to answer those questions; the reports are presented to the class (Preschlack, 2023). Children think hard and develop theories; for example, shapes representing the binomial and trinomial are first presented as hands-on puzzle cubes; older children are given information that leads them to realize on their own that these shapes embody the binomial and trinomial formulas for determining the volume of cubes, and even come to realize that they can figure out heptanomial and octanomial formulas on their own (Pottish-Lewis, 2021).

The Montessori teacher's role is to guide, by closely observing children and continuously and unobtrusively assessing their learning, offering interactive lessons to children who appear ready for the next level of difficulty. Another function of the teacher is to prepare the environment, to keep the apparatus of materials for the age level organized and in good condition (Montessori, 2012). Manipulative materials take on many functions that would be assumed by teachers in TTC environments. For example, Montessori materials make children's errors obvious, hence immediately self-correcting. There are sanctioned ways to use the materials, avoiding the pitfall of discovery learning wherein children do not make the intended discoveries. Instead of tests, assessments are given continuously but subtly during lessons, and children's public reports also show what they are learning.

Children teach and collaborate with each other. Multi-aged classrooms facilitate younger children learning from older ones, who cement their learning by teaching younger peers. Thus, Montessori is clearly a constructivist education, but one with a tightly organized structure.

Child-centered

In Montessori, every child is on an individualized learning plan, adjusted from a standard plan provided in teacher training. With age, Montessori children increasingly go out into the world for their learning in self-arranged small group field trips. There are no whole class field trips because every child chooses and designs their own way to learn, supported by the system and the teacher. Grades are not used, so motivation is entirely intrinsic; this conveys a feeling and attitude of self-determination. One's destiny is in one's own hands. The child is at the center, driving their own learning, free to find material that is in their current personal zone of proximal development.

In sum, in ways that make it consistent with today's child development research, Montessori is a highly structured, child-centered constructivist education, one that thrives on the interplay between children and a carefully created environment including a set of curated materials and a teacher trained to implement the method.

How CEI models address the TTC problems

A CEI model addresses the problems that led to the three major addenda described for the TTC model. First, grades are not needed to motivate in such a system. Children's intrinsic motivation to learn is higher in Montessori (Rathunde and Csikszentmihalyi, 2005) as it is in other child-centered classrooms (Stipek et al., 1995). The prevalence of free choice might explain this (Deci and Ryan, 2011). Because children are interested in what they freely choose to learn, no artificial extrinsic motivators like grades are needed to motivate children.

Second, children's uniqueness is not a problem in CEI classrooms, because at least in some CEI models teachers are not trying to give lessons to the whole class at once; they individualize instruction. Montessori originated with students with disabilities (Moretti, 2021), and inclusion has been an ongoing concern (Epstein, 2020). Children are free to learn at their own pace, and

to focus on their own needs and interests (which also increases motivation) as they interact with the environment. By ages 6–9, teachers are likely to present a material to a few children at the same level (for example, all ready for a specific grammar lesson), but at younger ages lessons are almost always one-on-one. A child with dyslexia can be given extra lessons in phonics, by a teacher or even by more knowledgeable students. A child who needs more or less structure can be given it; customization is built into the model.

Third, studies also suggest that at least in properly-implemented Montessori, children including those from groups typically disadvantaged in this country such as low-income children (Lillard et al., 2017) and children of color (Lillard et al., 2023b), achieve as good or better academic and social outcomes than children at other (typically TTC) schools (Denervaud et al., 2019, 2020b,c; Lillard, 2019; Snyder et al., 2022). One of the meta-analyses just cited used only studies with evidence of baseline equivalence; it showed that compared to traditional education, Montessori has significant positive impacts on both academic (reading, math, and so on) and non-academic (executive function, creativity, and so on) skills (Randolph et al., 2023). Proficiency levels on test scores are generally higher, and racial and economic achievement gaps on those tests are smaller (Snyder et al., 2022). Thus, with a CEI system, high-stakes tests have no problem to (try to) solve. In addition to doing getter on standardized tests and other measures of knowledge and skills, Montessori is associated with higher adult wellbeing (Lillard et al., 2021) and memories of liking school (Snyder et al., 2023) as well as liking school while in it (Rathunde and Csikszentmihalyi, 2005; Ruijs, 2017).

Of course, nothing is a panacea; widespread implementation of an alternative system would reveal issues with it as well, just as Copernicus's model required refinement following its widespread adoption. With Montessori education, a clear problem is retaining fidelity to the model; for reasons that are not yet clear, teachers sometimes revert to using TTC approaches like worksheets (Daoust and Murray, 2018; Daoust et al., 2019). But a model that better corresponds to how children naturally learn should work better than the current model, taking us out of the pendulum swings from TTC to unstructured discovery learning and back again. By moving children to the center, to the position of the sun in Copernican astronomy, and the onus of education to a structured set of well-designed and time-tested materials and methods, child-environment interplay models may be better able to help every child than is the ever-problematic TTC system. CEI systems are also well-aligned with culturally responsive education, supporting social justice.

How to get there?

A massive paradigm shift in our model of education cannot happen overnight, but since we have only used the TTC model for about 150 years, it might happen more quickly than the Copernican Revolution, which took over a century to displace several 100 years of astronomy. Here are some steps that might move things along.

1. First, more schools of education should offer CEI teacher training tracks. For example, the University of Hartford offers Montessori teacher training; Antioch University offers both Montessori and Waldorf. Currently many undergraduates do not even know that alternative systems exist, yet meanwhile alternative schools (especially public ones) are in dire need of more trained teachers. Montessori teachers report higher job satisfaction (Culclasure et al., 2018; Lillard et al., 2023a), so having alternative teacher education tracks might also help to address the current teacher shortage (Duncan, 2022).
2. States should automatically grant teachers who have graduated from approved alternative education training courses a state teaching credential to teach at schools offering the alternative model. Currently some states (such as South Carolina) do this for certified Montessori teacher training courses, but others require that teachers get additional training in teaching methods they will not implement, which getting Montessori training an added cost. The Montessori Public Policy Initiative helps states and districts with this.
3. States should allow for CEI assessments as they adopt reforms, recognizing that state tests are typically designed for a TTC model. CEI schools can present their own assessment methods, while being held to a standard as or more rigorous than that used in the TTC assessments. The National Center for Montessori in the Public Sector offers an Assessment Playbook to help public Montessori schools with this (see also National Center for Montessori in the Public Sector, 2019; Zoll et al., 2023).
4. Teachers at schools using alternative CEI models should be given the support of school heads who are also trained in the pedagogy, and who can provide strong parent education to help parents navigate a different model than they were schooled in. Excellent guidance on creating such schools is available (Slade, 2021).
5. Districts should convert one school at a time to CEI models. Many have done so with the Montessori model, resulting over 600 public Montessori schools at this writing (see Montessori Census at the National Center for Montessori in the Public Sector). Schools should begin converting to CEI models one classroom or level at a time, starting at age 3 and moving up, so children are prepared for the graduated levels of responsibility required in CEI classrooms. They should budget with the long haul in mind, since outfitting the environment can be more expensive up front, but will eliminate costs over time (for example, textbooks need frequent replacement that durable hands-on materials do not, and CEI models can require fewer teaching staff; Montessori suggests ratios of 1 teacher to at least 25, and preferably 40 children, and new evidence from my laboratory suggests that Montessori environments, unlike TTC classrooms, do function better with large ratios). To succeed, CEI classrooms should only employ teachers who have been certified by strong organizations to teach their pedagogy.

Summary

For roughly 150 years, the majority of schools have implemented a TTC model of education that is a poor fit to how children develop, and which has perpetuated social

inequities even while aiming to address them. Adjustments have been made to try to make the model work: grading and other extrinsic rewards, age-graded classrooms and tracking, and, most recently, high-stakes testing. But the problem, as Dewey and Montessori both pointed out over 100 years ago, is in the TTC model itself. COVID-19 and current events concerning racial equality have highlighted that schools and society are in crisis, and Chat GPT-like systems call into question our assessment approach. It is time for a paradigm shift in education, on a par with the Copernican revolution. With a highly structured environment of specially-designed learning materials and teachers who are trained to operate in that model, we can finally move away from the inadequate school model established in the era of industrialization and behaviorism. With such a change, all children will stand a better chance to flourish and take on the challenges of the 21st century.

> One of the most urgent endeavors to be undertaken on behalf of the reconstruction of society is the reconstruction of education … to awaken [children's] marvelous powers (Montessori, 1955/1989, p. 98)
>
> [Montessori] education may be figuratively described by saying that the educator stands behind the child and allows him to go forward as far as he can (Montessori, 1961/2007, p. 44)
>
> I am talking revolution! (Montessori, 2017b, p. 39)

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