Calibration of an agent based model of transgenerational processes and disparities in early life academic performance

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BRIEF ABSTRACT:

Early childhood academic readiness and success are early drivers of adult educational attainment, social status, and health. While there is important evidence for the role of pre-school educational opportunity as a predictor of primary and secondary school success, less is known about the relative contributions of transgenerational processes as mediated through pregnancy outcomes (preterm birth), or socioeconomic pathways. We use an agent-based model (ABM) to assist in contrasting the potential for policy interventions targeting persons (e.g. early childhood intervention or parenting classes), places (e.g. neighborhood amenities like preschool or elementary school quality), or transgenerational processes (e.g. targeting disparities in preterm birth or early intervention for children born preterm). The ABM includes 'mother', 'daughter', and 'neighborhood' agents with potential for residential mobility, socioeconomic trajectories, and the accrual of lifecourse 'Stress Scores' and 'Learning Quotient'. We describe the model structure, and provide calibration results to compare model-emergent properties with empirical observations.

INTRODUCTION

Early life cognitive and socio-emotional (non-cognitive) development are critical for children's school readiness and academic progress (1,2). Economic, racial and ethnic disparities in these early life developmental precursors set the stage for disparities in school readiness and subsequent academic success, with potentially lifelong economic, social, and health consequences (3–5). Underlying drivers of a child's developmental trajectories include genetics, in utero environments resulting in gestational growth restriction or prematurity, quality of parent-child social attachment, and family socioeconomic status including investment in child in the form of preschool, spoken language and text-density, and role modeling (6–8).

These child- and family-level 'drivers' or causes of inter-individual variation in cognitive and non-cognitive development occur in a larger social context. For example, a consequence of the history and persistence of residential segregation in the U.S. is that Black children from poor families are more likely to live in areas characterized by high poverty rates than are White children from similarly poor families (9,10). These areas may have greater social instability, lower social capital, and poorer performing preschool and early elementary educational services (3,11–13). Independent of individual socioeconomic status, preterm birth (a fetal 'insult' to development) is robustly linked to pre-school cognitive development, and school success (14–16). Preterm birth itself has biobehavioral and social determinants that originate during pregnancy, immediately before conception, or those that are evident going back as far as the mother's own early life experiences, highlighting birth outcomes as a possible mechanism for the transgenerational transfer of risk or resilience (17,18). However these fetal insults such as preterm birth are themselves socially patterned by race, ethnicity, and socioeconomic status (19). Non-Hispanic Black women have 50% higher risk of preterm birth, and 2-3 times the risk of very preterm birth compared to non-Hispanic White women (20). Together, this suggests that some children – particularly low-income children of color – may face double or triple jeopardy, with increased risk of fetal insults, increased risk of low family resources, and increased risk of residing in a neighborhood with high poverty and under-resourced educational services.

The complex interplay of these genetic, familial, and structural drivers potentially influencing child development – as well as between-group inequity in development and academic success – make it challenging to identify optimal public policy interventions that can target populations in highest need, and that are timed in the life course to address the developmental origins of child academic success. For example if racial or economic disparities in birth outcomes were an important driver of racial or economic gaps in kindergarten school readiness, or in third grade academic success, then renewed focus on preventing preterm birth and its sequelae, or on targeted early intervention for children born preterm might be impactful. On the other hand, if material and social investment in child pre-school environments were primary drivers, policies addressing both parent support as well as service allocation could be more impactful.

Agent based modeling (ABM) is a bottom-up simulated approach for encoding simplistic empirical findings in theoretically complex ways and evaluating emergent properties of the population (21). ABM's are composed of 'agents' (representing individuals or institutional players) which interact, adapt, and move through time making decisions using simplified heuristics. While rarely useful in isolation, the back-and-forth discourse from real-world questions and empirical results, to modeled 'populations' can advance future research, theory, and once well-calibrated, the models can provide a platform for policy makers and stakeholders asking 'what-if' questions (22,23). In this paper we calibrate an agent-based model designed to capture some of the dynamic interactions and relationships between families and children, between children and neighborhoods, and between mothers and children across generations, in order to quantify the contribution of each.

METHODS

The objective of the designed model was to answer the following questions

- What is the relative contribution of person-based (early childhood screening and intervention, vouchers for pre-school) or place-based (modifiers of residential segregation, location of Head Start services, quality of schools) interventions in reducing disparities in academic readiness and performance?
- What is the relative contribution of transgenerational processes including socioeconomic status and pregnancy outcome to cognitive development and academic readiness and performance?

Model structure

There are three agent classes: child, mother, and neighborhood; each agent class has attributes measured over time, which is incremented in 1-year units. Fathers and sibling are incorporated as attributes of the mother or child agent, rather than as distinct agent classes.

Mother – the model is initiated with a population of 10,000 women of reproductive age, differentiated by social status markers (e.g. 'class' or 'race'), and age. One fundamental parameter of the mother agent is her Stress Score. This is a composite of life-course factors promoting resilience or 'weathering' (allostatic load), and influenced by her physical health (chronic and infectious disease status as present/absent), mental health, and both individual and neighborhood-based socioeconomic status (24,25). Fertility rates are parameterized from US statistics to represent racial and economic variation in age-specific fertility. When a mother-agent becomes pregnant, the risk of preterm birth is determined by a small deterministic component (e.g. a shared 'genetic' risk for preterm birth) plus a probabilistic component derived from the mother's age and her Stress Score (higher stress score increases risk for preterm birth; lower stress score reduces risk; conditional on age). Mother's reside in neighborhoods composed of other mother's/families. A Schelling-like model for residential mobility is used, wherein agents move to improve neighborhood amenities with availability of alternatives constrained by individual SES.

Child – there are two primary properties of the child agent: her Learning Quotient (LQ, representing a composite inherited + acquired learning potential); and her Stress Score. The LQ is initialized to be an average of the mother's LQ and 100. A child's LQ is decreased if born preterm, and can increase or decrease each year through primary school as a function of mother's stress score (e.g. her physical and mental health), socioeconomic status, and family structure. Presence or absence of neighborhood amenities including pre-school can increase/decrease early life LQ. The child Stress Score is initialized at zero, but is adjusted to reflect family and neighborhood experiences; therefore the accrual of protective or positive experiences reduces the Stress Score, whereas the accrual of negative family or place-based exposures and opportunities increases it. A child's performance in school (measured at kindergarten and 3rd grade) is a function of her LQ, family socioeconomic status, and neighborhood amenities including school quality. In other words it is possible that a child with a lower LQ could perform well with a mother with lower Stress Score, or in a neighborhood with more amenities.

Neighborhood – neighborhoods are initialized with realistic racial/economic segregation patterns, and corresponding amenities and school quality features. As agents move, the amenities/school quality are modified by the economic status of current residents. 'Affordability' or availability is similarly a function of average socioeconomic status; thus there is an ability to relocate to 'better' neighborhoods, but there are constraints on what is affordable.

Model Process

To calibrate the model, we initialize and run the model for 200 years, tracking lifecourse patterns of social mobility, LQ, and Stress Score, and tracking the transgenerational transfer of LQ as mediated by Stress Score, a heritable component, and family/neighborhood environment of early life.

Anticipated Results

Currently the model reproduces expected social disparities in preterm birth and child academic performance in Kindergarten and 3rd grade, and transgenerational correlation in each. We anticipate summarizing calibration of social mobility as a dynamic process (e.g. emergent from interactions between persons and places and across generations). Further parameter sweeps will be conducted to assess the sensitivity of calibration findings to initializing states, or to adjustment in the heuristics driving within-person and between-generation parameters. Ultimately we will explore the impact of 'fixing constant' or 'eliminating' one of the hypothesized pathways to child academic performance including:

fetal insults in form of preterm birth; transgenerational social class; early childhood family SES; early childhood neighborhood SES; and school quality and neighborhood amenities.

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