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The timing of educational investment: A neuroscientific perspective

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ABSTRACT

Economic models of investment in human capital sometimes refer to neuroscience as a means to support their underlying assumptions regarding human development. These assumptions have a crucial influence on the policy implications the models generate. We review the extent to which the neuroscience of development can be used to support a "learning begets learning" principle of human capital accumulation. We conclude that, although early neural development can be considered as foundational, it cannot be considered as a unitary phenomenon that proceeds in continuous fashion. Furthermore, the concept of the sensitive period, which is often used associated with the principle, suggests benefits of investment depend upon an individual's circumstances and developmental history, and particularly whether this can be classified as normal. A more recent model of investment has involved two different types of abilities, with outcomes demonstrating the value of including more sophisticated assumptions about human development. We conclude that, while current discussions of policy would benefit from a more careful interpretation of existing models, the potential for future work combining modern neuroscientific understanding with economic theory is considerable.

1. Introduction

In 1997, Hilary Clinton addressed an audience of educators at the Whitehouse and told them "It is clear that by the time most children start preschool, the architecture of the brain has essentially been constructed" (Bruer, 1999). This conference, held during the "decade of the brain", has been cited as an important moment in the history of the "myth of three". This is the myth that 0–3 years is a critical period of human development after which the trajectory of development is fixed. Amongst other things, this myth has helped promote ideas about "hot-housing" normally developing children with a highly enriched educational environment, in the belief this will bring about returns that are disproportionate with later educational experiences. Some of the evidence used to support this myth has been drawn from studying the effects of enriched environments on learning and the development of synapses (Diamond et al., 1987; Greenough et al., 1987). However, this research involved laboratory rats living in environments that were no more enriched than their natural habitat. This is despite the researchers themselves pointing out that their enriched condition was an incomplete attempt to mimic a wild environment and was enriched 'only in comparison to the humdrum life of the typical laboratory animal' (Greenough et al., 1987, p. 546). Other evidence associated with the myth includes developmental changes in the brains of animals (Boothe et al., 1979; Cragg, 1975), before human studies showed similar changes extending into early adulthood (Huttenlocher, 1979). In the last decade, there have been several attempts to explore these ideas and promote a more scientific and balanced awareness amongst educators of how neural processes over the life cycle support and may, sometimes, constrain human learning (Blakemore and Frith, 2005; Bruer, 1997; Howard-Jones, 2010).

However, ideas from neuroscience are increasingly of interest not only to educators but also to those who develop educational policy. In particular, the idea that the young

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brain is more plastic appears potentially relevant to those targeting government spending on education and training. The putty-clay model of people (we become harder to change as we age) (Leonard, 2000) has a common sense appeal to it, and it places an appealing emphasis on the youngest in our society which is difficult to resist. At the same time, the idea of accumulating mental capital (Foresight, 2008) within such a developmental constraint is also easy to understand. When simple ideas about human development resonate with common sense, they gain extra utility in policy making and policy communication. The addition of neuroscience, with its seductive allure (Weisberg et al., 2008), can further add to the persuasive nature of a message. As reviewed below, ideas from neuroscience are now finding their way into formal models of economic investment that are proving influential in policy making. While integration of economic, educational and developmental perspectives may prove invaluable in informing future educational policy, it is important that any alleged application of neuroscience is scrutinised for its scientific limitations. Here, we first describe the types of intervention research that have given rise to the "learning begets learning" principle before describing the model of educational investment based upon it. We briefly consider why neuroscience might be viewed as an alternative attractive source of evidence to support the assumptions underlying this model, before critically examining the extent to which this can be achieved. We consider the implications for the "learning begets learning" principle of a more recent model, and consider how work at this important interface of economics and neuroscience may develop in the future.

2. Earlier is often better

There is clear evidence that early educational interventions can provide long-lasting effects into adult life. Multiple studies show early experiences of childcare can improve later outcomes in cognitive, language, and social development (Burchinal et al., 2008; Peisner-Feinberg et al., 2001). For example, in the UK, the Effective Provision of Pre-School Education (EPPE) Project showed that, irrespective of level of multiple disadvantage, 'home' children (those who had little or no preschool experience) showed poorer cognitive and social/behavioural outcomes at entry to school and at the end of year 1 than those who attended pre-school. These 'home' children were more likely to be identified by teachers as having some form of special educational need and, by the end of Key stage 1 (when aged 6–7 years), the attainment gap was still evident for reading and mathematics (Sylva et al., 2004). The extent to which differences in early educational experience appear to predict later outcomes can be striking. A recent U.S. study of non-relative child care from birth to 4.5 years has shown that higher quality care predicts higher cognitive-academic achievement at age 15, with escalating positive effects at higher levels of quality (Vandell et al., 2010). The STAR project in Tennessee showed a correlation between the experience of a child's kindergarten teacher and their future adult earnings (Chetty et al., 2010). The Perry study showed that a high-quality 2 year preschool program for young children living in poverty contributed to their intellectual and social development in childhood, as well as their economic performance and reduced criminality in adulthood (Schweinhart et al., 2005). Such studies demonstrate the potential for substantive long-term benefits of early intervention on cognition, socio-emotional development, school progress, antisocial behaviour, and even crime. In contrast, a review of eleven employment- or education-focused programs for high school dropouts, all of which had been rigorously evaluated, showed little evidence of effects lasting beyond 20 years (Bloom, 2010).

3. The "learning begets learning" model of investment

Although influence is likely to be bidirectional, education is considered an important contributor to economic growth. Relatively high literacy levels are thought to have contributed to the ferocious growth of Asia's tiger economies in the 1980s and early 1990s, with a lack of well-qualified graduates considered to be restricting economic growth in India (Keeley, 2007). The funding of education is often referred to by economists as a form of investment in human capital (Becker, 1993). Early work in the economics of human capital linked the time profile of investment with the life cycle of earnings (Becker, 1962) and examined, for example, the relationship between interoccupational differentials in annual pay and differences in length of training (Mincer, 1958). This literature assumed ability was fixed at very early ages, suggesting human capital and innate ability were rival determinants of earnings. This was criticised at the beginning of the last decade by James Heckman, who argued that economic models of human capital should include a concept of ability that is not fixed but is, itself, influenced by investment (Heckman, 2000a). Heckman and colleagues reasoned that the skills attained at a point in time can have a bearing on subsequent skill (self-productivity). Furthermore, investment at a point in time can have a bearing on the productivity of later investment (complementarity). These two factors combine in the model such that "skills beget skills and abilities beget abilities" (Cunha and Heckman, 2007). This original simple model makes two important predictions: that early investment should be followed up by later investment in order for the early investment to be productive (which is supported by behavioural evidence (Statham and Smith, 2010)) and that, all else being equal, the earlier in life that investments are made, the greater the economic return.

The notion that external factors can influence our ability to learn represents a significant step towards a model of human capital that is more in line with understanding of human cognitive development. The principle of "learning begets learning" can be used to derive graphical expressions of the effects of investment at different ages, as shown in Fig. 1 (Knudsen et al., 2006).

4. Misinterpretation of the model

Fig. 1 shows how this modelling of return can lend graphic emphasis to the benefits of early investment. However, it should be emphasised that this graph is not a plot of empirical data but the graphical expression of an

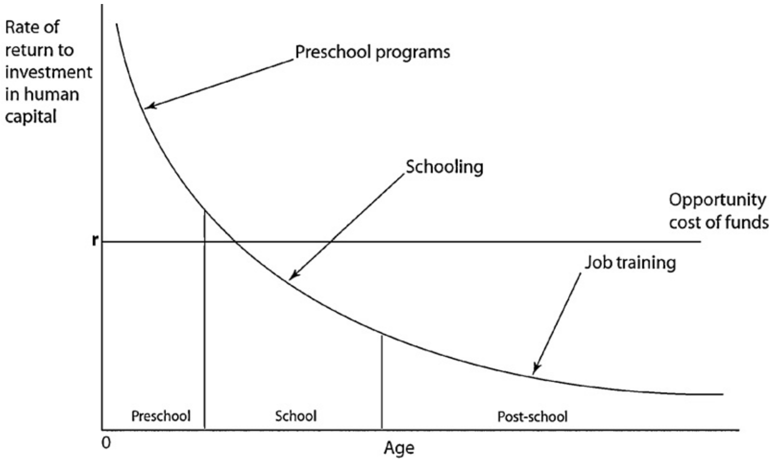

Fig. 1. Rates of return to investment in human capital as function of age when the investment was initiated. The data were derived from a model human capital accumulation with multiple periods and credit constraints. Investments were initially set to be equal across all ages and "r" represents the cost of the funds.
Data are from Cunha et al. (2006).

economic theory. This is an important point, because even when fitted to authentic data, models built on assumptions tend to express those assumptions. Unfortunately, when non-specialists view a graph derived from such a model, they may easily misunderstand it as *evidence* for the model's assumptions. A recent example can be found in a publication by the UK's Centre for Social Justice, where it states this graph "shows that investment early in life produces better returns", when it might more appropriately be said to illustrate the economic implications of this assumption (CSJ, 2011). Another misinterpretation is to consider this graph recommends an "optimum curve of investment for Government (including local government)" as suggested by Hoskin and Walsh (2010, p. 65). Rather than show an optimal weighting of expenditure for government, the graph shows the return on a marginal dollar, i.e. beyond that which is already invested, with all else remaining equal. A major shift in the distribution of funding would likely change the return on any further marginal investment (Heckman, 2008a).

5. The attractiveness of identifying neuroscience evidence to support "learning begets learning"

Despite studies demonstrating the potential effectiveness of early intervention reviewed above, the timing of an intervention makes no simple prediction of its likely effectiveness. Two major US initiatives (Head Start and Early Head Start, with a budget in 2011 of 8.1 billion dollars) have shown gains dissipating within 2–3 years (Barnett, 2011), while a study of adolescents matched with mentors showed they were less likely 18 months later to have started substance abuse or hit someone, and more likely to have improved their academic performance, attitudes and family relationships (Tierney and Grossman, 1995). Thus, considerable uncertainties exist regarding the design of effective interventions across childhood, and the failure of some interventions in the past does not infer the failure of all interventions in the future. Indeed, when reviewing existing studies of early interventions, it has been pointed out by Mervis that these interventions are unable to answer questions about the best methods or timing required to maximise return (Mervis, 2011). It is beyond the scope of this paper to review the evidence from interventions but, if one accepts the view of Mervis (2011), then it becomes questionable whether such evidence alone can support simple assumptions about the optimal timing of investment and the validity of the "learning begets learning" principle.

Since the evidence from intervention studies might be viewed as incomplete, finding a biological basis for this principle is an attractive possibility. The concept of the sensitive (or critical) period appears to suggest that closing windows of opportunity exist in childhood when neural circuitry is particularly prone to sources of potential enhancement such as formal and informal education. Seen in this way, neural development appears like a pyramid whose height and breadth is tightly constrained by the size of previous layers no longer amenable to further extension. In other words, the limits of later investment are set by earlier investment, and we seem to have biological support for the "learning begets learning" principle. When assumptions associate themselves with neuroscience, however, it can be argued that particular scrutiny should be applied. It has been experimentally demonstrated that including neuroscience in an explanation can add to the satisfaction it provides, even when irrelevant (Weisberg et al., 2008). In order to examine the scientific basis of the "learning begets learning" principle and its associated investment model, we will now briefly review what is known about neural development. In particular, we will focus on the existence of critical or sensitive periods, which is often used as scientific evidence for the value of early education.

6. Neuroscience and development

The behavioural evidence for the importance of early experience does not conflict with our understanding of brain development, since we know the first few years of life to be a period of fundamental organisation at the neurological level. It seems not unreasonable, therefore, to consider childhood as providing foundations for future learning (Bailey, 2002). These foundations are established through a continuous series of dynamic interactions between genetic and internal/external environmental influence (Friederici, 2006; Grossman et al., 2003; Hensch, 2004; Majdan and Shatz, 2006). Although the vast majority of our lifetime's supply of neurons arrives within 3 months of our conception, dramatic changes in *connectivity* between these neurons (synaptogenesis) tend to occur in waves throughout childhood. After birth there is a massive increase in synaptogenesis, i.e. there is a huge blossoming of connections (or synapses), such that the infant's brain is more connected than an adult's. Then follows a wave of synaptic pruning, in which connections are cut back. These changes occur at different rates in different regions of the brain. For example, in some regions of the occipital lobe (associated with vision), the number of connections peaks at about 8–10 months whereas, in parts of the frontal and parietal lobes (associated with many types of reasoning ability), the decline begins around the beginning of puberty, reaching adult levels at around 18 years or later (Huttenlocher and Dabholkar, 1997).

7. Sensitive, critical and optimal periods

Learning is possible across the lifespan, and this reflects the brain's lifelong ability to change its connectivity, i.e. its synaptic plasticity. However, neuronal activity moderates the influence of experience and environment that shape the development of neural circuits. For this reason, atypical input to a neural circuit during waves of synaptic proliferation and pruning is thought capable of producing atypical functioning of circuits that is more difficult to reverse than if it had occurred in the absence of such waves (Tau and Peterson, 2010). It has been known for some time that atypical events in the external environment of young animals, such as sensory deprivation, can radically influence development if they occur within a certain period after birth but have considerably less impact if they occur later or earlier (Hubel and Wiesel, 1970). The periods in time when the development of a neural circuit can be particularly influenced by the environment generally occur early and so, although the brain never exhausts its potential for further change, neuroscience conceptualises early brain development in terms of some progressive restriction of fate (Johnson, 2004). These periods, whose time course and function vary in different regions of the brain, are usually known as sensitive periods. (More strongly, if effects are considered entirely irreversible, they may be called critical periods.)

A famous example of a sensitive period is our ability to distinguish between speech sounds. We have much greater difficulty in doing this if we have not heard the speech sounds before we are 6 months old (Kuhl et al., 1992). This makes it more difficult to learn a language containing these sounds in adult life. As an example of a sensitive period, later remediation is not impossible but learning outside of this period will be more difficult. The concept of the critical period can be used to explain why congenital cataracts in human infants, if not corrected by 6 months of age can produce irreversible impairments in the visual system. Increases in synaptic pruning, as well as proliferation, are also considered to sensitise a period of development (Hooks and Chen, 2006). Pruning has been linked to the shedding of redundant synapses, e.g. with synapses that transmit weaker and less organised patterns of activity becoming less active and ultimately being eliminated. If disorganised or atypical input occurs during a wave of pruning, it can be assumed that more synapses required for typical functioning will be eliminated than if this input occurred later.

8. Known sensitive periods occur early, but later ones probably exist

The clearest physiological and behavioural evidence for human sensitive periods is restricted to primary types of function (e.g. motor and sensory process). The sensitive periods for human sensory systems occur chiefly in the first 1–2 years of life (Lewis and Maurer, 2009; Werker and Tees, 2005) although sensitive periods for some aspects of vision close much later (e.g. peripheral vision in the early teens (Lewis and Maurer, 2005)). The development of some primary cognitive functions can include those expected to influence the higher-order thinking processes that build upon them. This may help explain why early deprivation can lead to later educational problems, but also why very early intervention can considerably reduce their likelihood. For example, while the IQ of typically developing children can be reduced to the low 70s as a result of being placed in poor institutional care at birth, placing such children in high-quality foster care before the age of 2 years dramatically improves their IQ by 3–4 years old (Nelson et al., 2007).

The evidence for sensitive periods in later childhood involving higher-order processing is more difficult to find. This may be due to the highly challenging nature of studying sensitive periods in humans, as opposed to animals. This has caused some researchers to claim only 10 years ago that such research was virtually impossible (Bailey, 2002). Emerging evidence, however, suggests late sensitive periods may exist. While regions in the brain involved with primary sensory processing mature early, the prefrontal cortex appears to be one of the last brain regions to mature (Casey et al., 2000) and it is this region that, perhaps more than any other, is thought to govern complex adaptive responses to changing environmental demands (Mackey et al., in press). The extended plasticity of the human prefrontal cortex (including continuing processes of synaptic proliferation and pruning, and myelination) is thought to be reflected in the continuing development of a range of executive functions throughout childhood and adolescence (Blakemore and Choudhury, 2006). Indeed, emerging neuroimaging-based evidence indicates that adolescence may also be a special time for learning from social experiences and this hints at the opening and closing of periods of increased sensitivity to environmental influence (Nelson and Guyer, 2011). For example, while most other regions of the brain are influenced by atypical adversity in early in life, the prefrontal cortex appears more vulnerable to such experiences when they occur during adolescence (Andersen et al., 2008).

The medial prefrontal cortex is a key region for the processes of mentalizing, in which we interpret the actions, gestures and faces of others in terms of their possible underlying mental states and emotions. This is an ability which is still developing during adolescence (Blakemore, 2010). There is a reduction in the activity generated in the medial prefrontal cortex during mentalizing tasks between adolescence and adulthood, with evidence that connectivity between this region and other parts of the mentalizing network varies with age (Catherine et al., 2008). Since we know structural changes are still occurring in the frontal lobes, it might also be expected that a range of executive functions are still showing improvement during adolescence. However, the rate of improvement is not continuous or uniform across functions. In a study of performance on a variety of executive function tasks between the ages of 11 and 17, a linear improvement in performance has been shown on some tasks (e.g. selective attention, working memory and problem solving) but not others (e.g. strategic behaviour) (Anderson et al., 2001). While the relationship with neural development remains the focus of nascent research, the behavioural evidence indicates different aspects of executive function have different developmental trajectories (Blakemore, 2010). Pubertal dips have been reported in the ability to name facial expressions (McGivern et al., 2002), and to recognise (Carey et al., 1980; Diamond et al., 1987) and encode faces (Diamond et al., 1987). Another study has demonstrated that improvement in prospective memory (the ability to remember one's intention to do something) levels out between 10 and 14 years old before improving again in early adulthood (Mackinlay et al., 2003). Changes in the levels of neurotransmitters associated with the opening and closing of sensitive periods provides further evidence suggesting such periods may exist beyond infancy. From studying the early development of sensory and motor processes, the neurotransmitter gamma-aminobutyric acid (GABA) has been identified as having a key role in processes involving sensitive periods (Dayan and Huys, 2009). For example, returning to the development of visual regions, researchers have altered GABA circuitry to demonstrate they can cause animals of the same age to peak at different times in their receptiveness to environmental influence (and either before or after their normal sensitive period) (Heekeren et al., 2004). Interestingly, GABA changes are not restricted to the early years but have been found to occur across the lifespan in the human brain (Pinto et al., 2010). Although the most convincing physiological and behavioural evidence for sensitive periods is presently constrained to the early years of infant development, such indirect evidence has prompted the reasonable hypothesis that such periods also occur later, including during adolescence (Blakemore, 2010). Until we know more about the specific role of sensitive periods, the significant structural and connectivity changes that occur into early adulthood suggest that all childhood is potentially a special time for learning. We know abilities differ in the rate at which they develop, with some following non-linear trajectories.

9. The putative relationship between sensitive periods and education

In education, it has been observed that expertise in a curriculum area is influenced by the time when learning began (Aunio and Niemivirta, 2010; Crone and Whitehurst, 1999). In areas such as second language learning, age of acquisition effects have led to suggestions of a critical period (Borghans et al., 2008). However, firm evidence of sensitive and critical periods derives from scientific studies of change in constrained sets of neurobiological processes in specific regions of the brain, together with changes in closely associated neurocognitive function. Educational learning, in contrast, involves performance in complex tasks that require the recruitment and interaction of a very broad range of such processes and functions. In the example of second language learning, the rate at which performance improves may be influenced by developmental changes in a variety of capabilities subserving acquisition. These changes may occur in parallel but at different rates. Therefore, if sensitive and critical periods play a role in observable patterns of educational learning, this role would probably involve the overlap of several such periods. There may not, therefore, be any simple relationship between our emerging understanding of sensitive periods and educational performance in a particular curriculum area. Indeed, an extensive review of age of acquisition effects and second language learning seriously questions the value of the critical/sensitive period concept in this area of education (Munoz and Singleton, 2011). More broadly, it seems unlikely that sensitive periods will, in the near future, help determine when we should best learn any particular topic. No neural data has been yet reported that supports the notion of sensitive periods in relation to curriculum areas or topics within them (Thomas and Knowland, 2009). To avoid confusion, it has been suggested (Koizumi, in press) that we should refer to periods when we most easily learn educational topics as *optimal periods* for learning, to make clear the distinction between these and critical/sensitive periods.

10. Sensitive periods may help understand abnormal rather than enhanced development

Healthy neural development is an important part of the foundations for later learning and it relies upon the interaction of healthy environmental and genetic influence. Abnormal development is considered to arise from the involvement of atypical genetic and/or atypical environmental factors. Studies suggest a substantial genetic influence on learning difficulties (Haworth and Plomin, 2010), which demonstrate a more substantial genetic component than most common psychiatric disorders (Plomin, 2008). Sufferers of these difficulties also benefit most from intervention when it occurs early. The most hopeful of the many interventions for dyslexia have been targeted at children up until 6–7 years old (for review see Shaywitz et al., 2008). Fewer interventions have been attempted for dyscalculia, but the reported successes have also been targeted at this young age group (Kucian et al., 2011; Rasanen et al., 2009; Wilson et al., 2009). The experience of atypical deprived environments are being demonstrated by adopted children from institutions in Romania who, if they had experienced these environments beyond the age of 6 months, were mostly demonstrating impaired functioning in follow up studies when aged 11 years (Kreppner et al., 2007; Rutter et al., 2007). Again, early interventions have been shown to greatly improve the cognitive, linguistic, and emotional effects of such impoverished experiences (Ghera et al., 2009; Nelson et al., 2007; Windsor et al., 2007). When, as in these cases, the remediation of difficulties rests upon the early timing of exposure to more enriched environments, then it is reasonable to hypothesise that sensitive periods are playing a role. However, what we know about sensitive periods derives chiefly from identifying periods when an atypical environment gives rise to abnormal development. Therefore, the success of enriched environments in ameliorating such abnormal development before the sensitive period has expired should not be taken as evidence that an enriched environment can deliver similar gains to children with typical genetic and environmental backgrounds, who have not been severely disadvantaged in either respect (Monsell, 2003). The greater impact of enrichment for the less advantaged is suggested by evidence that children living in poverty benefit more than others from early educational settings that are high-quality, with children with special educational needs demonstrating longer-term benefits (Phillips and Lowenstein, 2011).

In the area of special needs education, it should not be assumed that early intervention will obviate the need for later investment. It is considered unrealistic to think of earlier intervention as an alternative to later intervention when problems have become established: both are needed (Statham and Smith, 2010). However, there are examples where early action has succeeded in preventing the need for later intervention, and the future use of neural markers for the earliest possible identification of risk may further contribute to these successes (Szucs and Goswami, 2007).

11. The neuroscience of the "learning begets learning" principle

The early years can be considered as foundational in the sense that neural circuitry developing that contributes to the ability to learn later in childhood. Also, neural plasticity diminishes with age for all individuals, with the neural and behavioural effects of some very early atypical experiences difficult to reverse in later years. However, in the light of the above review, we would suggest that a "learning begets learning" principle falls short of what we know of development in several important ways:

(i) We have seen that the neural concept of the sensitive period emphasises the value of avoiding an atypical environment, but may not predict the same advantage again when normal development encounters an enriched environment. Therefore, outcomes are not likely to arise simply from the history of investment in an individual's "skill stocks", but may also depend critically on the extent to which their development, and the influences upon it, can be characterised as normal. The model does not differentiate between typical and atypical experience and genetic background.

(ii) Human development and learning is not unitary. Instead, the evidence suggests a range of interrelated neural circuits subserving a range of human skills. Crucially, these may develop at different rates until early adulthood.

(iii) Human development and learning is not continuous. Given the structural changes that continue to occur through adolescence, and associated discontinuous development of some cognitive functions (Blakemore and Choudhury, 2006), it is entirely possible that some sensitive periods begin in later childhood (see above). From behavioural evidence, it also appears that children may not learn to tackle problems such as spelling in a continuous fashion, e.g. by becoming faster at the processes they use to tackle a problem, but may develop by ceasing to use one set of processes in favour of another, entirely different, set of processes (Frith, 1980). In contrast to this complex picture, the model assumes a single type of accumulating cognitive ability.

Additionally, of course, some types of learning may not be amenable to the earliest intervention. Progress in some important areas will requires individuals to have reached a level of maturity in terms of understanding and decision-making, and both behavioural and neurocognitive research suggests such development continues across adolescence. Some of this development is associated with the type of self-regulation that benefits academic success, but it can also pertain to contexts where external constraints additionally apply. That is, successful intervention in these areas may also rely on individuals being at, or close to, an age when they are granted the responsibility and/or opportunity to rehearse the appropriate judgement (e.g. traffic safety when cycling, sexual relationships and contraception, use of alcohol, etc.). Deriving "real world" implications of the model is not, therefore, straightforward.

These factors can be illustrated in the following example. Imagine we wish to make an intervention aimed at improving the ability of normally developing children to take appropriate risks when they later become young adults. When should such an intervention take place? The simple "learning begets learning" approach might suggest the earliest intervention. We must remember, however, that these individuals are already assumed to have typical development derived from an expectable environment and normal genetic background. Therefore, early interventions, although potentially having greater effect than a later one, may not show such great benefit as for those whose trajectory is threatened with abnormal development. Secondly, risk evaluation is an area that may suffer discontinuous development: there is evidence that teenagers have more difficulty in making appropriate decisions than either their older or younger counterparts (Baird et al., 2005; Steinberg, 2007). This suggests that adolescence may be an important time for learning about risk. More speculatively, a sensitive period related to risk evaluation may open after early childhood, with the reward system during adolescence showing increased sensitivity to reward when making risky decisions (Van Leijenhorst et al., 2010). This presents a biological argument why the earliest intervention may not be appropriate. And, of course, in the contexts encountered in adolescence and with the increasing freedoms that teenagers enjoy, decision-making tendencies can have much greater consequences than those of younger children (e.g. regarding sex and drugs). Interventions in their earliest years cannot fully incorporate these important contexts and may not be appropriate.

12. The political implications of the "learning begets learning" principle and model

James Heckman was awarded the Nobel prize in Economics in 2000 and has become one of the most influential of today's economic thinkers. The "learning begets learning" principle and its associated model was generated at a time when emerging studies were suggesting that the long term benefits of early education might have been under-appreciated (Blau and Currie, 2006; Schweinhart et al., 2005). This model has done much to ensure that the needs of younger children are not overlooked. In discussions about students funding their own higher education in the UK, the economic model of investment has also been used to support the statement that "social gradients in access to higher education, and equity in educational attainment more generally, are primarily determined by cognitive development in early childhood" and "expanding higher education based on contributions from those who benefit from it rather than based on general tax revenues is the most direct way to ensure equity in education outcomes" (OECD, 2004). Even in recent narratives iteratively developed through interdisciplinary discussion between neuroscientists, developmental psychologists, paediatricians, economists, and communications researchers, the phrase "skills beget skills" features as an important part of the core story (Shonkoff and Bales, 2011). Possibly its power lies in metaphorical links to financial capital accumulation and so provides a durable cultural model that is a convenient approximation for non-scientists to make sense of their world (Bales and Gilliam, 2004). Indeed, before any formal model was published, a conceptualisation of learning and development may already have existed amongst non-specialists that was allied with ideas of capital accumulation and the so-called Matthew Effect.[1]

Heckman's ideas stimulated considerable discussion when they were published in 2000. Apart from researchers wishing to point out examples of effective later interventions (Blundell, 2000; Palme, 2000), it was also noted that this simple model highlights a potential trade off between equality and efficiency that is inherent in the "learning begets learning" principle. That is, as concluded by Leonard (2000), Heckman's model calls for redirecting educational investments as early as possible "towards the (human capital) winners and away from the losers." In response, Heckman claimed it encouraged equality by highlighting how early intervention could counter an adverse family environment more efficiently than a later intervention (Heckman, 2000b). Yet it remains evident that the "learning begets learning" principle, and the model that makes its implications explicit, promises greater return from investing in a child that has not already suffered from an adverse environment (as in Fig. 2, reproduce from Heckman's original paper (Heckman, 2000a)).

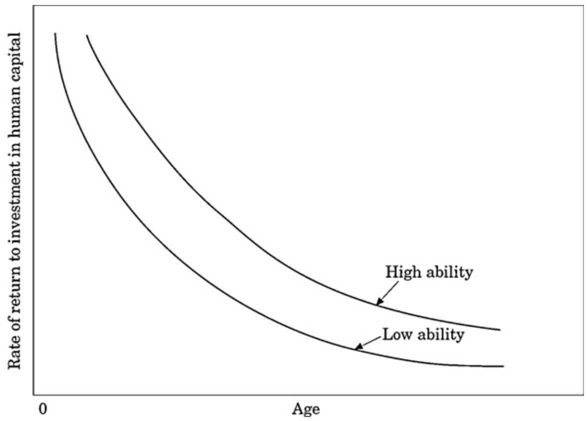

Fig. 2. Rate of return to investment in human capital for different abilities. These were calculated (Heckman, 2000a) using the model described in Fig. 1. According to the model, low ability individuals provide poorer returns than their higher ability peers.

The fact that the model predicts an equality-efficiency trade-off cannot, of course, be considered as evidence that the model is flawed. However, when a model generates outcomes that conflict considerably with existing policy, this does highlight the need for confidence in its underlying assumptions.

13. Models of educational investment rest upon their scientific assumptions

More recent work in this area has demonstrated that even a small step towards a more scientifically informed model of educational investment can have a major influence on the policy implications that are generated (Cunha et al., 2010a). This work builds on reflections regarding the effects of early deprivation on brain development, to further emphasise the likely importance of investing in the earliest years (Heckman, 2008b). Although Heckman's original theory of skill formation did not differentiate between different types of skill, this later work sought to differentiate between two sets of mental skills: cognitive and noncognitive skills. The term "cognitive" is used by researchers Cunha and Heckman to mean factors such as IQ and achievement tests, while "noncognitive" is used to refer to factors sometimes considered as personality traits, such as motivation, socioemotional regulation, time preference, personality factors, and the ability to work with others (Heckman, 2008b). This cognitive/non-cognitive division is primitive and potentially confusing, since few aspects of human behaviour are devoid of cognition (Borghans et al., 2008). Also, attempts to justify the division are not well founded on scientific understanding. For

[1] For whosoever hath, to him shall be given, and he shall have more abundance (Matthew 13:12).

example, these attempts include associating greater malleability in these "noncognitive" skills (relative to cognitive skills) during adolescence with lag in adolescent prefrontal brain development (Heckman, 2008b). Yet the prefrontal cortex is also associated with a range of executive functions (such as working memory and higher level reasoning) that fall under the classification of "cognitive" skills. Arguments made in the economic literature (Cunha et al., 2006) for this division also point to claims (Aiyagari et al., 2002) (also situated in this body of literature) that it is hard to change IQ after 10 years old. However, the scientific literature does not support this limitation (Buschkuehl and Jaeggi, 2010), with recent examples of IQ being raised by modest interventions involving young adults (Jaeggi et al., 2008, 2010). Indeed, in a recent study of training executive switching function in three age groups (mean ages 9, 22 and 69 years), similar and significant transferable improvements were found in all three groups (Karbach and Kray, 2009).

We saw above that a model that lumps all mental skills into a single category might suggest greater economic returns from investing in children who have been advantaged rather than disadvantaged by their early experiences. Cunha et al. (2010a) fitted their new model to data from 2207 children who had been assessed every 2 years for their cognitive, non-cognitive skills and home environment (CHRR, 2004). Investment was measured in terms of those family activities that the data itself suggested were influential, e.g. "How Often Child Goes on Outings at Ages 1–2", "How Often Mom Reads to Child During Year of Birth". When the model was formulated solely in terms of cognitive skills, it suggested the optimal policy was to invest relatively more in the early years of the initially *advantaged*. However, when both cognitive and noncognitive skills were included, it was optimal to invest early in the less advantaged, suggesting that ignoring the interrelationship between these two sets of skills was enough to produce a misleading guide to public policy (Cunha et al., 2010b, author's manuscript). To maximise returns, the model suggests optimal early investment involves favouring the deprived, with optimal later investment only slightly tilted towards the more advantaged.

Further analysis of the new model's outputs emphasised the specificity of its implications, e.g. that the optimal timing of interventions for disadvantaged children depended on the conditions of disadvantage and the desired focus of the intervention, taking account of the types of skills involved (although categorised only as cognitive or noncognitive in this model). Cunha and colleagues used their model to consider two specific types of outcome: educational attainment and crime. For the most disadvantaged, Cunha et al.'s model suggests the optimal policy for maximising educational outcome is to weight investment towards the early years, with crime reduction benefiting more from later investment. Note that the advice is for a preferential weighting, and does not suggest focusing entirely on the early years. Indeed, in this sense, the model advises against a radically disproportionate focus. Moreover, the ratio of optimal early-to-late investment greatly declines with advantage, i.e. optimal investment for more advantaged children is less about weighting investment towards the early years.

Such a result is convergent with notions of early sensitive periods as discussed above, i.e. periods during which development is particularly vulnerable to not receiving typical environmental stimulus, rather than particular sensitivity to enhanced development from enriched environmental stimulus. The model also helps counter the idea that the early years provide hot-housing opportunities for advantaged children to gain special enhancement of their potential. The Cunha et al. model is also congruent with scientific understanding in some other respects. For example, it expresses the prediction that optimal early-to-late weighting of investment is much less when remediating noncognitive skills rather than cognitive skills. In this sense, the model does not conflict with the views of those neuroscientists who argue that adolescence may also be a sensitive time for learning, especially since these researchers suggest such sensitivity may include social learning processes (Blakemore, 2010), i.e. a type broadly associated with Heckman's noncognitive processes. However, the underlying assumption that the development of mental abilities can be considered in terms of only two broad categories remains at odds with current scientific understanding. For this reason alone, caution is required in drawing policy implications from its predictions.

Also, the model predicts outcome in terms of human skill formation that is considered of economic benefit, but there is no simple relation between this outcome and its economic consequences. For example, due to the increased independence and physical capabilities of teenage children, it is possible that small, unfortunate but normal features of developmental trajectory (e.g. increased risk taking) can have very costly consequences (e.g. pregnancy (Rosenthal et al., 2009), smoking (Markham et al., 2008), addiction (Chambers et al., 2003)). These aspects of behaviour are amenable to cost-effective intervention. So, it seems likely that comparable gains (in terms of economic benefit–cost ratio) can be achieved by well-targeted and well-designed interventions in later years, as they can in early years. For example, enhancement of working memory, together with associated improvements in fluid intelligence, has been achieved during adulthood through relatively short interventions (Jaeggi et al., 2008). And, even in much later life, targeted educational interventions may still offer significant economic benefits. For example, computer-based cognitive training is seen as a promising therapy to maintain brain health and reduce risk of dementia (Steinerman, 2010), a disease which incurs direct costs to the NHS and Social Care of £8.2 billion annually (Department_of_Health, 2010), and up to £17 billion when indirect costs such as the lost earnings of carers are included (Alzheimer's_Society, 2007).

14. Conclusions and reflections

Combining concepts from cognitive developmental science, economics and education in models of investment may provide powerful tools for the policy makers of tomorrow. Understanding about sensitive periods may contribute to these models, helping to explain why earlier educational interventions are often better, at least in cases of abnormal development. However, most of what we presently know about sensitive periods is restricted to the early development of primary processes, despite indications that periods influencing other aspects of cognitive development may exist in later childhood. The direct implications of sensitive periods for those working within education are limited, since we have not yet identified such periods for school-age children that are related to curriculum areas or topics within them. Should these periods be identified, their relationship to educational learning will be complex, since this type of learning involves many diverse and interrelated cognitive processes.

Sensitive periods have chiefly been studied in the context of abnormal development in response to atypical stimulus. Despite this, they have been used to promote the enhancing effects of enriched environments on normally developing children, as well as to justify models of educational investment that explore outcomes across the ability spectrum. These attempts to integrate neuroscience into economic models of investment began with a model based on a simple "learning begets learning" approach that did not differentiate between different types of skill. Even so, the model provides a striking graphical expression of the general effectiveness of early intervention that such a principle suggests, as well as illustrating how follow-up funding may be needed when investing in the disadvantaged. However, this model can be misinterpreted by policy-makers as evidence, rather than expression, of the principle itself. Given the model's salience in present political and even interdisciplinary discussion, there is a need for greater awareness that the model assumes development is unitary, continuous and independent of whether an individual and/or their circumstances can be characterised as normal. These assumptions place limitations upon interpreting any implications generated by the model, including prediction of an equity/efficiency trade-off that favours investment in the more advantaged.

The most recent model attempts to distinguish between (two) types of skill. When fitted to existing behavioural data, it suggests that investment should be weighted towards the early years, with greatest benefit from early investment in the disadvantaged. It also suggests that interventions in adolescence benefit more from a focus on "non-cognitive" skills, such as motivation and self-regulation, rather than "cognitive" skills. This demonstrates how the scientific basis for a model can critically influence its policy implications. We do not know, for example, how the inclusion of three or more types of skill might influence implications further. Therefore, even results from this more recent model should be interpreted with some caution, since its scientific assumptions remain contentious.

In the future, models may integrate economic models with the increasingly complex models of human development and cognition that draw more closely on neuroscience. These might include investment beyond those activities more traditionally associated with educational benefit considered by Cunha et al. (2010a). They may, for example, draw on recent neurobiological research suggesting socioeconomic disparities in educational outcome are amenable to investment aimed at preventing, reducing, or mitigating the effects of toxic stress on the developing brain (Shonkoff, 2011). Above, we have also seen that existing models already emphasise that the questions of "when" and "who" are very bound up with the question of "what" abilities are being targeted. Future models might be usefully informed by recent research on the potential of education to enhance very fundamental abilities such as executive functions, which are central in supporting skills that include flexibility, self-control, and discipline (Diamond and Lee, 2011). Our analysis has also highlighted the extent to which the validity of any such model depends crucially on the extent to which it is able to incorporate current scientific understanding of development. Ideally, future models might include what is known about the development of networks considered crucial to the production of different skills and abilities, including the development of connectivity between component regions. Techniques such as network analysis, which can reveal the evolution of age-specific functional brain networks, may be helpful here (Chu-Shore et al., 2011). These new techniques have allowed researchers to demonstrate that, at each stage in normal neurodevelopment, age-specific skill sets correlate with age-specific distributed brain networks, and that these progress in a manner which can be nonlinear and nonincremental, but which is still predictable. For example, recent work involving network analysis has demonstrated how the default mode network (which is considered to support, amongst other abilities, our introspection) is only sparsely connected in children aged 7–9 years, compared to the strong functional connectivity observed in adults (Fair et al., 2008). Consideration of the normal developmental trajectory of this and other networks across childhood should suggest how abilities might be mathematically characterised grouped and interrelated most conveniently and appropriately. This would allow a more reasoned approach to defining an approximation for what is, in reality, a large and diverse set of abilities that are supported by an overlapping, interactive and developing set of networks. Indeed, in the appendix of Cunha et al. ((2010a, supplementary material, p. 7), the authors note that introduction of a new non-cognitive skill at a later stage in childhood can, according to their model, increase the extent to which later investments in these skills can substitute for earlier ones. Such advances may eventually help identify the optimal period of investment for particular types of ability. However, it must be accepted that the mathematical challenge in developing such sophisticated models may stall their production for some years yet. Until then, policy-makers might benefit from greater care when deriving messages from models of educational investment that attempt to combine neuroscience, cognitive development and economics, with particular attention to the assumptions on which these models are based.

Conflicts of Interest

The authors declare not to have any conflict of interest.

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