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Paradigms from the Science of Learning: An Emerging Revolution in Education

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Abstract

In the last few centuries, scientific break-throughs in the physical sciences delivered the industrial revolutions. It is now the turn of the human sciences, which are at the point of generating social revolutions. This paper posits that our scientific understanding of human learning has matured to a point that it provides clear guidelines on how to revolutionise education. The paper identifies and explores five key paradigms that are starting to revolutionise education: (1) Neuroplasticity, Cognitive Load Theory and Chunking are three critical discoveries that, blended together, describe how learning takes place; (2) the Theory of Flow shows how to make learning enjoyable; (3) there are two distinct modes of thinking; (4) cognition is integral with sensory/motor, emotional and social operations; and (5) neurobiological circuitry matures in a predictable pattern of sensitive periods. The paper then explores three implications of this revolution for education. Firstly, infancy and toddlerhood are critical periods of and for learning. Secondly, the science of learning can be systematically taught in schools, to ensure that all citizens become independent/autonomous learners, capable of life-long learning. Universal higher education within affordable public expenditure is in our grasp. And thirdly, universities have the crucial responsibility of transforming themselves to best enable this social revolution in the wider society. This paper analyses evolving concepts to predict and propose a future – an ambitious task. Before concluding, the paper critically reflects on its analysis - its limitations and risks.

Introduction

Over 50 years ago the physicist turned historian Thomas Kuhn introduced the idea that science progresses through periods of long, slow maturation, with periods of sudden, sharp, revolutionary paradigm shifts (Kuhn, 1962, 1970). One such paradigmatic shift was the Copernican revolution, which shifted the earth from the centre of the universe to a small, insignificant planet in one of a multitude of galaxies. The renewed interest in and maturation of the physical sciences enabled the industrial revolution, a period of burgeoning improvements in global material wealth. This material success imprinted (Marquis & Tilcsik, 2013) in society a belief and trust in the physical sciences and its reductionist method.

Many of the most famous scientists of that period were not linked with universities. Michael Faraday, Francis Bacon, Benjamin Franklin, Daniel Fahrenheit

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and James Watt are just some of the many scientists who worked outside the university framework. And universities, continuing to teach the traditional subjects of grammar, rhetoric, dialectic, music, arithmetic, geometry and astronomy lost touch with the needs of the modern industrial society. It took the Humboldtian revolution, in which universities adapted the reductionist method of the physical sciences, of requiring and permitting narrower and narrower specialisations of their schools and professors, for research and relevance to return to universities (Enders, 2006; Perkin, 2006). Today, the Australian Bureau of Statistics (2008) specifies 1,238 research domains.

While progress in the physical sciences has accelerated ahead, progress in understanding the biological, social and cultural aspects of human life – Human Science (University of Oxford, 2017) - has been much slower. It is not that there has been no progress – rather, our knowledge in these sciences is less. Our practical applications of these sciences are less reliable. The methods of the physical sciences – of reduction, quantification and mathematization – haven't worked as well for the human sciences.

Today, earth is increasingly shaped by human activity, and the most intractable problems we seek to resolve are human problems: global warming; waste management; multi-generational disadvantage; interpersonal violence – to name just a few *Wicked* problems (Australian Public Service Commission, 2012).

We instinctively feel that the key to these issues lies with improving education. Yet education itself is a very human system, shaped over centuries by our cultures and stakeholders. How do we reformulate education, and what scientific paradigms offer us guidance?

Wendell Bell (1997, 2003), in proposing Futures Studies as a rigorous discipline, called it a human science for a new era. He noted that "thinking about the future is a universal phenomenon that can be traced back to the dawn of human prehistory" (p2). This paper takes the position that we are experiencing a scientific revolution in Human Science. Human Science is coming of age. Human Science is at the cusp of delivering solutions to wicked problems. A social revolution comparable to the industrial revolution.

The paper has two principal sections. The first section makes the case that our understanding of human learning, primarily through work in neuroscience and cognitive psychology, has reached a point where our knowledge allows us to transform Education. The section makes the case by exploring five key constructs. Our understanding of how humans learn is now sufficiently mature for it to be systematically taught. Doing so will create a society of independent learners[1]. A society where citizens have the ability to take charge of and further their own education. A society where every adult could continue learning and developing skills, without requiring high levels of public funding.

The second section examines the impact of this revolution on education. The section explores education's role in enabling this revolution as well as how education institutions will need to transform themselves to continue to be relevant.

Before concluding, the paper briefly critically explicates its theoretical approach and explores its limitations and weaknesses.

Five Constructs on Learning

The purpose of this section is to present four important developments in our understanding of learning: to substantiate the central argument that learning can now be systematically taught as a science that students can learn and apply to design and take control of their own learning: "Give a man a fish, and you feed him for a day; show him how to catch fish, and you feed him for a lifetime"[2].

(1) Neuroplasticity, Cognitive Load Theory and Chunking

Broadly speaking, unlike with most other cells, the human body stops producing new neurons in early childhood[3]. However, what does grow (and reduce) are the neurons' ability to send and receive signals – termed neuroplasticity (Draganski et al., 2004). This is what causes learning. Memories appear to be the connections between cells and their ability to send and receive signals.

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[1] There are many definitions of independent (and autonomous) l earning (Broad, 2006). Common themes in these definitions include: (1) cognitive skills; (2) emotional (affective) skills such as motivation and resilience; (3) an ability to design their instructional environment for optimal learning; and (4) access to necessary resources.

[2] Perhaps deriving from the Chinese proverb 'Who teaches me for a day is my father for a lifetime' (Knowles, 2009)

[3] Research using more accurate equipment shows that there is continuing generation of new neurons in two regions, the hippocampus and the striatum, and this regeneration may have a role in brain function and learning. Neurons also have some ability to move (as distinct from stretch) from one region of the brain to another (Ernst & Frisén, 2015).

Memories appear to correspond to minute physical changes in the brain.

Cognitive Load Theory (Sweller, van Merrienboer, & Paas, 1998) divides memory into two components: (1) a working memory that is used for thinking and manipulating ideas, but is only capable of holding a few ideas, and only for short periods, and (2) a long-term memory that is virtually unlimited in size and can store information for very long periods.

Chunking is the process by which neurons group together, so that when one fires, then they all fire. These connections also allow more complex thought. Human working memory is only capable of holding a limited number of thoughts simultaneously. When ideas are chunked together, the chunked set of thoughts take up only one slot in working memory, allowing other ideas to be simultaneously processed.

Learning requires repetition. When material hasn't been chunked by sufficient repetition, then learning more complex material will be more difficult. Just learning material is not enough – it needs to be learned well. Optimal tactics for the development of long- term memories include (a) repetition; (b) spacing – repeating delivery of the same material several days later; (c) recall – requiring the student to recall the memory rather than it being provided; and (d) association with other existing memories (Oakley, 2014). There is even increasing evidence that overlearning (practicing beyond where there are noticeable improvements in performance) delivers important benefits (Shibata et al., 2017) .

(2) The Theory of Flow

Mihaly Csikszentmihalyi's Theory of Flow (Cheron, 2016; Csikszentmihalyi, 1991; Csikszentmihalyi & Asakawa, 2016; Nakamura & Csikszentmihalyi, 2014) describes an optimal state of mind in which a person is immersed and focused on their activity. To achieve Flow, a person must be working on material that gives immediate feedback on whether they are succeeding or not, and they should be succeeding most of the time but not always. The activity should not be too hard nor too easy[4]. Adee (2012), in a fascinating Scientific American article, *"Zen and the art of genius"* describes current research by the US military.

Neurochemical activity explains the importance of immediate feedback. Immediate positive feedback connects pleasure with the correct answer as well as the test-taking process. Delays in feedback and the resultant uncertainty causes anxiety in the student, heightening the likelihood of negative associations. Excessive success creates satiety and boredom.

These two constructs thus give a model for best instructional design:

(a) Material must be broken down (de-chunked) into bits the student is familiar with. This design step is a learned skill. Discipline experts without this skill make poor teachers, since in their mind the material is highly chunked, and they do not appreciate the level of de-chunking necessary.

(b) The de-chunked material should be presented using the tactics of (i) repetition; (ii) spacing (iii) recall and (iv) association with existing memories until the material is chunked and in long-term memory.

(c) This process needs to be neither too hard nor too easy for the student.

(d) Regular and rapid feedback is important.

(e) When students are struggling to learn new material, this shows that earlier material has not been sufficiently chunked into long-term memory. Continuing the student on the same trajectory is counter-productive and harmful. The student needs to go back and practise earlier material until it is chunked and in long-term memory. Formative assessment prior to starting new learning material is essential as it verifies that earlier material has been chunked and stored in long-term memory.

(3) Two Modes of Thinking

Kahneman, a psychologist who won the Nobel prize in Economics for his work on human decision-making brought the existence of two distinct modes of thinking into widespread public awareness though his book *Thinking, Fast and Slow* (Kahneman, 2011). Kahneman describes it well, arguing that most decisions are made in System 1 (Fast) mode, but when asked to explain the reasoning behind the decision, the System 2 (Slow) mode comes up with a rational explanation for the decision. Expert chess players, for example, don't usually rationally plan future steps. Rather, they map the current board layout to board layouts in memory and choose which ones are most associated with success and move pieces towards the best layouts. Experts are those with a phenomenal memory of board positions (Kahneman & Klein, 2009).

[4] An enhancement to the concept of flow is that of Deliberate Practice (Anders Ericsson, 2008; Ericsson, Krampe, & Tesch-Römer, 1993). The authors studied the training of elite performers – those who achieve national and international recognition, in comparison to more pedestrian performers. Elite performers devoted more time to what the authors termed Deliberate Practice – effortful, focused attention to identifying and correcting errors. As such, Deliberate Practice is a state beyond Flow: the practice is not pleasurable, but delivers more efficient, effective learning than Flow.

Very similar, yet subtly different groupings of the characteristics of and labels for these two modalities have been put forward by various scholars from different disciplines (Table 1):

Table 1: The concept of two modes of thinking, as expressed by different scholars

Scholar	Discipline	Labels	
Kahneman (2011)	Psychology	Slow (system 2)	Fast (System 1)
Fox et al (2005)	Neuroscience	Task Positive Network	Default Mode Network
Cole & Schneider (2007)	Neuroscience	Cognitive Control Network	Autobiographic Memory Network
Oakley (2014)	Education, Engineering	Focused	Diffuse

Advances in medical imaging have allowed us to map specific brain regions that increases activity during certain types of thoughts. When a subject is asked to perform calculations or other demanding mental task, specific areas of the brain become more active and other areas become less active. Fox et al. (2005) have labelled the former as the "Task Positive Network" and the latter as the "Default Mode Network" respectively.

Evans and Stanovich (Evans, 2008; Evans & Stanovich, 2013) provide a useful analysis of the characteristics of these two types of thinking as discussed in the psychological literature (Table 2).

Table 2: Commonly ascribed attributes of each type of thinking*

Type 1 process (intuitive)	Type 2 process (reflective)
Defining features	
Does not require working memory	*Requires working memory*
Autonomous	*Cognitive decoupling; mental simulation*
Typical correlates	
Fast	Slow
High capacity	Capacity limited
Parallel	Serial
Nonconscious	Conscious
Biased responses	Normative responses
Contextualized	Abstract
Automatic	Controlled
Associative	Rule-based
Experience-based decision making	Consequential decision making
Independent of cognitive ability	Correlated with cognitive ability
System 1 (old mind)	System 2 (Evolved late
Similar to animal cognition	Distinctively human
Implicit knowledge	Explicit knowledge
Basic emotions	Complex emotions

Note. Italicized attributes are the proposed defining characteristics in the current article. Authors proposing two systems include the features attributed to Type 1 and 2 processing but may also include the additional features named.

* From Evans & Stanovich (2013): Table 1. Clusters of Attributes Frequently Associated With Dual-Process and Dual-System Theories of Higher Cognition

Oakley, in collaboration with Sejnowski, a computational neuroscientist, developed a course, "Learning How to Learn" delivered through the on-line platform Coursera (Oakley & Sejnowski, 2014). This course is currently ranked as the world's most popular Massive Open On-line Course (MOOC) of all time and is presently available with four language subtitles. Major elements of the research discussed in this paper is available to the public and is rapidly spreading.

A frequent expectation from education is the ability to innovate. The concept of two modes of thinking suggests that there could be two distinct approaches to enabling innovation: using System 1 thinking, which aligns with a popular use of the word *"creativity"* and using System 2 thinking which aligns with a popular use of the phrase *"critical thinking"*. Thomas Edison and Salvador Dali are famous historical examples of the deliberate exploitation of the former (Oakley, 2014). Both would think about a problem and doze, holding an object. As they started to doze, they fell into a light dream state – System 1. They drop the object they were holding, and the noise woke them, the thoughts in their mind at that time often providing inspiration. Sleeping on a problem and breaking off a period of intense work to go for a walk are other tactics that exploit this thinking method.

Alternatively, an example of critical thinking would be De Bono's (1987, c1985) six thinking hats: a method for deliberately managing the thinking process and examining the problem from different angles (such as critically or optimistically). Another teachable method would be through the identification of cognitive biases and societal ideologies: understanding weaknesses in existing ways of thinking maps potential analytical pitfalls.

This duality may provide insight into differences sometimes seen between some Eastern and Western students. An approach which emphasises developing strong analytical skills develops minds with deep, sophisticated discipline knowledge, but less able to release the mind for creative thinking. Minds trained for broad, holistic approaches may have weaker analytical skills and depth, but are better at creative thinking. Different types of meditation may strengthen the neural networks for each type of thinking. Techniques that build the ability to maintain concentration, such as the Chakra or the Anapanasati meditation techniques of gently bringing the wandering mind back to the focus of thought, may improve system 2 thinking, while open monitoring mediation, such as Vipassana may help the development of

System 1 skills (Oakley, 2017)[5].

(4) Cognition is integral with sensory/motor, emotional and social operations

Currently, education focuses on cognitive abilities - an emphasis, a privileging of analytical over sensory-motor, emotional and social operations. A construct inherited from a dominant western philosophical tradition. The brain itself is wired integrating all its functions, and separating one activity from another is an artificial reductionism. Optimal human functioning depends on skills in all these areas that develop from birth[6]. At birth, infants must bond with their mothers for survival – sensory-motor, emotional and social skills. Recognising faces and smiling, for example, requires complex muscle movements that are practised and improved early in life. The early neural networks continue to develop as children find their place in their tribe, sensing and responding to the emotional cues of others: “that male is angry – avoid him or risk broken bones”.

These multi-faceted skills, inadequately addressed by our education system, are crucial in the modern world. Reading requires eye movements (saccades) learned in infancy. Children with a rich oral vocabulary learn to read faster. Dale Carnegie, though not a scholar, popularised the importance of non-cognitive skills in his iconic *How to Win Friends and Influence People* (Carnegie, 1936). Since then, several scholars have stepped in, drawing from recent research to address this gap in our education system. Eckman’s (2007) *Emotions Revealed,* Cialdini’s (2007) Influence and Patterson et al’s (2012) *Crucial Conversations* are just a few[7].

Perhaps most valuable in our increasing integrated understanding of emotions is with regards to the importance of stress and anxiety[8]. Stress is a valuable biological mechanism, delivering improved concentration and physical power in moments of danger. However, highly stressful situations can cause trauma, and chronic stress causes significant physical and mental damage. In education, exam stress is a recognised major issue (Asghari et. al., 2012). The techniques for noticing and training one’s emotions can be taught at schools and universities.

Different parts of the brain do not grow (and prune) simultaneously, implying that different types of learning occur most economically and effectively at different periods (Thomas and Johnson, 2008). To quote from the National Scientific Council on the Developing Child (2007):

> *“The basic architecture of the brain is constructed through an ongoing process that begins before birth and continues into adulthood. Like the construction of a home, the building process begins with laying the foundation, framing the rooms, and wiring the electrical system in a predictable sequence, and it continues with the incorporation of distinctive features that reflect increasing individuality over time. Brain architecture is built over a succession of “sensitive periods,” each of which is associated with the formation of specific circuits that are associated with specific abilities. The development of increasingly complex skills and their underlying circuits builds on the circuits and skills that were formed earlier. Through this process, early experiences create a foundation for lifelong learning, behavior, and both physical and mental health. A strong foundation in the early years increases the probability of positive outcomes and a weak foundation increases the odds of later difficulties.”*

A measure indicative of sensitive periods is synaptic density. Figure 1 shows how synaptic density rapidly increases, peaks and then drops and flattens out. The density of the visual and auditory cortices (areas involved with vision and hearing) peak before the prefrontal cortex (associated with complex behaviour).

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5 Schools of meditation often mix multiple techniques.

6 The Center on the Developing Child at Harvard University (2014) promotes three core concepts: that (a) experiences build brain architecture; (b) Serve and Return Interactions shape brain circuitry; and (c) toxic stress derail healthy development.

7 Reading and writing, on which our education system focuses, is an evolutionarily recent communication method. Human biology and tribes evolved to support communication by sound and body language. Tone and body language are powerful means of communication. Face-to-face communication may thus be a critical requirement for establishing trust. As such being able to produce and interpret tone and body-language are important skills. And tone and body language are used differently by different cultures. They appear to be picked up by children early in life and become automated, subconscious.

8 That is not to subtract from other emotions that are important to learning. Motivation, drive, and resilience, for example, are all skills with strong emotional components. They involve interactions between the nervous and endocrine systems that are the subject of active research. The dotted line is of the auditory cortex,

Figure 1. Synaptic density at various parts of the cortex at different ages. From Huttenlocher and Dabholker (1997)

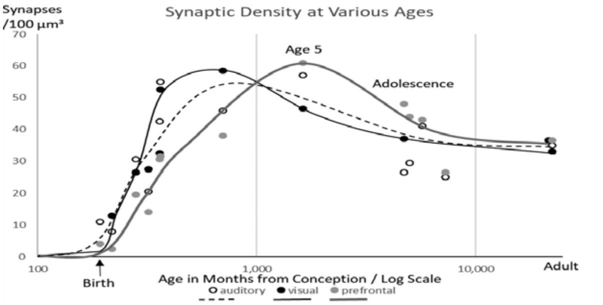
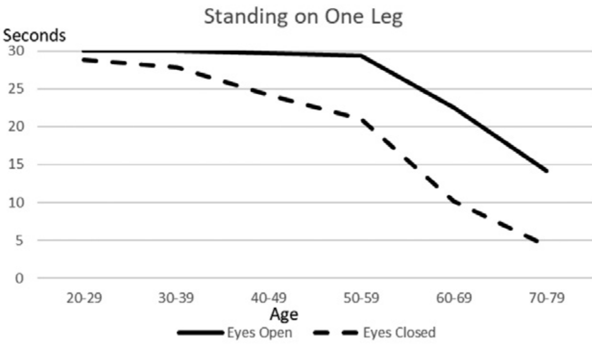


Figure 2. Deterioration in balance as we age. Functional deterioration is measurable from the early thirties. Data from Bohannon et. al. (1984).



The existence of sensitive periods and the chunking of learning emphasises the importance of infancy and toddlerhood. Two other development periods are also worth emphasising. Firstly, puberty starts dramatic physical and mental changes. Puberty is a sensitive period for decision-making, emotional and social neural pathways (Peper and Dahl, 2013; Suleiman & Dahl, 2017). The development and reinforcement of behaviours at this stage lead to the fixation of habits that have long-term positive or negative outcomes.

Secondly, after peaking, neurobiological skills gradually but increasingly deteriorate. This deterioration may initially be subtle and not noticed. Figure 2 illustrates our reducing ability to balance as we age – doing so with our eyes closed begins by the thirties[9]. On the other hand, neurobiological skill reduction is initially more than compensated by increasing knowledge (and knowledge-workers typically continue to increase in value for several decades). However, this deterioration can be slowed (and even stopped) by undertaking hard (i.e. demanding, unpleasant) physical or mental activities (Barrett, 2016). The bulk of society is adults, and education must understand adult neurobiology. Education has a responsibility to communicate this knowledge to the public. Since such hard work includes mental work such as studying for a degree or learning a foreign language, it is imperative that education makes suitable resources available to the public at minimal cost[10].

While education currently has models of cognitive development (e.g. Piaget and Erickson), there is a significant scope for improving the effectiveness and cost of education by designing delivery to take advantage of recent advances in our understanding of human neurobiological schedules.

Impacts on Education

Learning occurs in many ways. A common categorisation is informal learning - such as a toddler learning to walk, or a parent reading with a child, and formal learning - deliberate, systematic, institutional. This paper suggests that developments in the science of learning indicate three areas as of primary importance for implementing changes that facilitate a social revolution.

(1) Infancy and toddlerhood

Infancy and toddlerhood are periods when the greatest neural growth takes place. Motion and communication are just two of the complex skills they learn that require the successful integration of many different neurobiological elements. It is the period that arguably receives the least educational funding yet offers the greatest potential for savings, not only in education but also in other major expense areas such as health, social welfare and criminal justice (McCain & Mustard, 1999). A child's brain is shaped by both its genes as well as its environment (e.g. experiences)[11]. Research indicates that

[9] Three sources integrate to create our 'sense" of balance: (i) the vestibular system, (ii) the eyes; and (iii) sensory nerves though-out the body. The vestibular system is a set of three fluid-filled canals in each, each at right angles to the other, to allow motion to be sensed in any direction. Integrating information from the three sources and getting our muscles to respond is learned in infancy and childhood, and becomes habituated so that it happens without us paying attention to it (Cherng, Chen and Su, 2001).

[10] This is not to imply that mental exercise is the only contributor to mental health. Good diet, physical exercise, positive social interactions, adequate sleep and the avoidance of damaging stress are also some important contributors to good mental health.

[11] A popular public debate, often called 'Nature versus Nurture'. Unfortunately, the debate, couched in language forcing it to be either one or the other, clouds the truth that it is both (Rettew, 2017).

the environment has a greater effect during the early years, and less in later years (Plomin et. al., 1997)[12] .

The Center on the Developing Child at Harvard University (2014) promotes three core concepts: that (a) experiences build brain architecture; (b) Serve and Return Interactions shape brain circuitry; and (c) toxic stress derail healthy development. For example, children who are encouraged and allowed to exercise their sensory-motor skills learn to walk earlier than those raised in more subdued cultures (Karasik et. al., 2010). Children who learn to move and walk earlier are better able to experiment with their environment, strengthening an even greater range of brain mechanisms. Serve and Return (think of a game of badminton) is an action-response sequence between a baby and carer. It develops communication skills and builds trust - if the communication is positive. Which leads to the Center's third concept – toxic stress. While stress has benefits, both high levels of stress (mental trauma) and chronic stress creates significant damage to the brain. This damage may be subtle and initially, unnoticed, but have very harmful long-term consequences (Heim & Binder, 2012; Smoller & Ressler, 2015). Emotions are contagious (Wild, Erb, & Bartels, 2001). Stress in one person is often passed onto another. Even skilled professionals are not immune. Front-line staff working with difficult families may themselves become stressed, adding to the problem[13].

Especially damaging is collective trauma - events such as war or a tsunami that damage whole communities. Not only is there psychological trauma to the individual, but the family and community are also "traumatised" (Somasundaram, 2014). Family and community leaders may be killed or injured. Key infrastructure such as that providing food, shelter or health services may be damaged. These often take years to build, which means that children suffer, not only from an acute incident, but continue growing up in a highly stressful environment.

A direct teacher-student relationship is inappropriate with infants. Rather, the strategy should be on improving child-rearing practices based on the science of learning (Phillips & Shonkoff, 2000). A Parents as First Teachers approach (Praat, 2011; The National Education Goals Panel, 1997). Ideally, strategies would focus not only on the parents, but extended families. *"It takes a village to raise a child"*[14]. This becomes particularly important in single-parent families, or when the parents themselves are damaged or over-worked. Community organisations, including religious organisations may be valuable in furthering appropriate strategies.

Government education departments do not have the experience or infrastructure to implement strategies for infants. Education departments operate teaching systems based on classrooms grouped together to form schools, colleges or universities. On the other hand, health departments have infrastructure for the health-care of infants. Health departments also have a public health sector with expertise in community outreach activities. It may therefore be optimal for health and education departments to provide an integrated service. Physical health, mental health and early learning have many overlapping elements.

(2) Schools

School represents an opportunity for direct, systematic teaching by skilled professionals. Children are developing the skills necessary to sit quietly and concentrate so that teaching can be done in classroom thereby lowering costs.

While infant and childhood strategies are aimed at delivering healthy children to the school system, the role of schooling provides the heavy lifting – transforming children into effective independent learners – the key to creating a truly social revolution that changes not only education but all of society. To systematically create independent learners requires the science of learning to be a formal part of the school curriculum, on a par with, if not more important than mathematics and language. And just as maths, language and science has a theoretical component and an applied/practical component, the curriculum needs to have both theoretical and practical components[15,16].

[12] General cognitive ability, 'g', is a well-studied metric. Plomin (1999, citing McGue et. al, (1993)) states that heritability of 'g' is "found to increase from about 20 per cent in infancy, to about 40 per cent in childhood, to 60 per cent or greater later in life".

[13] Burn-out and high turn-over of front-line staff are often symptoms of institutional failure to address stress among staff.

[14] An African proverb, it is also the title of a chapter of a documentary on advances in neuroscience on the crucial role of the early years of children's lives (Renner, 2016). The documentary, supported by UNICEF and private foundations, is available for public viewings at no cost.

[15] Understanding theory helps students in three ways. Firstly, having an integrated understanding of both theory and practice assists in creating coherent, long-term memories. Secondly, the science of learning is rapidly evolving. Understanding the theory helps understand and contextualise new research. Thirdly, students with a deep understanding of theory are less likely to fall for false theories – neuromyths (Dekker et. al., 2012).

[16] Neuroscience as a discipline is particularly hard to learn because it has its own language - one needs to learn neuro-anatomy: the structure of the nervous system and the medical terms that describe each component.

Along with neurobiological aspects of learning, independent learners need to understand instructional design principles. Understanding the principles of instructional design allows learners both to design their own learning as well as better understand and use the instructional frameworks they are taught in. Teachers can do this by engaging students even from early years in the framework of the curriculum and how and why certain teaching practices are adopted. By making the instructional design framework explicit, both the students and the teacher form a partnership to ensure a strong instructional design framework[17].

Of particular importance is formative assessment[18]. It is essential that both the student and the teacher know what the student doesn't know (or knows insufficiently), since if these areas aren't fixed, then subsequent elements that are dependent on this prior learning will be more difficult and frustrating. Students also learn during assessment - they are reviewing and recalling the curriculum material, strengthening neural connections. Frequent assessment consolidates current knowledge and directs the student on how to proceed in their learning.

Creating quality assessments is a difficult and time-consuming skill. Nevertheless, one can perhaps not have too much testing (Nelson, 2016). It is therefore essential to ensure that when curriculum material such as textbooks are developed, so too must sufficient assessment tools.

Learning by teaching is an age-old concept (Seneca, c. 65 AD). Teaching of students by fellow students can help both the learner (Johnson & Bailey, 1974) and the student-teacher (Dineen, Clark & Risley, 1977). Learning by teaching younger students is a particularly useful method of getting children who haven't sufficiently chunked material in previous years. For example, a fifth-grader with weak age-appropriate language skills may refuse to practice reading third grade material, but would cheerfully do so when the task is presented as teaching a younger student (Giesecke, Cartledge & Iii, 1993). Learning by teaching not only helps learn the content skills being taught, but may also be used to help reinforce the science of learning and the skills needed for independent (and interdependent) learning[19].

The sensitive period of adolescence occurs during the school years. While the changes are wide-ranging, a useful simplification may be to view the period as two sequential stages. First, the centres involved with emotions develop. Emotions tend to be stronger, and memories tied to these emotions appear to be more easily retained. Later, system 2 executive functions related to emotional control and delaying gratification are strengthened. During this period of heightened emotion, without the corresponding ability to control them results in high risk behaviour and greater susceptibility to certain mental illnesses (Giedd, Keshavan & Paus, 2008).

Just as existing health institutions may be better placed to deliver education outcomes during infancy, schools may be better placed to deliver better physical and mental health outcomes during the school years. And beyond: life-long skills. To ensure life-long skills, it is insufficient to simply teach the requisite knowledge and skills. The practice of these skills must become habits: resulting from system 2 thinking rather than only relying on system 1 thinking.

(3) Universities

To understand universities, it is useful to understand their cost structure. In exploring the costs of systems, it is useful to differentiate between fixed costs and variable costs – the distinction being that fixed costs do not vary with the number produced, but variable costs do. At an earlier SEEAIR conference, the authors showed that of the different elements of systematic learning needed in a knowledge economy[20], delivery – actual

[17] Key elements of good instructional design is captured by what Biggs (2014) calls 'constructive alignment': "an outcomes-based approach to teaching in which the learning outcomes that students are intended to achieve are defined before teaching takes place. Teaching and assessment methods are then designed to best achieve those outcomes and to assess the standard at which they have been achieved".

[18] Nicol & Macfarlane□Dick (2006), in promoting formative assessment for independent learners, review the literature and synthesize seven principles to be met for good quality assessment. "Good feedback practice: helps clarify what good performance is (goals, criteria, expected standards); facilitates the development of self-assessment (reflection) in learning; delivers high quality information to students about their learning; encourages teacher and peer dialogue around learning; encourages positive motivational beliefs and self-esteem; provides opportunities to close the gap between current and desired performance; and provides information to teachers that can be used to help shape teaching."

[19] While increasing teaching by students is an excellent strategy that could also reduce the workload of professional teachers, there are a number of practical difficulties. Firstly, managing a facility where the curriculum includes periods when children are teaching other children requires significantly greater skill and co-ordination by the professional teacher.

[20] That is: (i) the establishment of learning outcomes; (ii) the design of delivery; (iii) delivery; (iv) assessment; (v) accreditation; and (vi) maintenance.

teaching - was the most expensive variable cost (Somasundaram, Bowser, & Danaher, 2006).

However, attempts to reduce such costs, such as through massive on-line courses and examinations with minimal teaching, result in very high numbers of drop-outs and exam failures. Too many students aren't independent learners. Students are aware of this issue, typically preferring blended learning opportunities (Tanchaisak & Wattanapanit, 2016). The key argument of this paper is that we now have a sufficiently robust understanding of how learning occurs, to the point that these skills can be effectively taught and assessed.

It is essential, though, that all students be competent independent learners. One therefore needs to have a systematic, regulated process. Universities can adopt one or more of several tactics:

1. Establish a university entrance exam to assess independent learning skills;

2. Develop enabling courses that teach independent learning skills; and

3. University Education faculties influence the development of a learning science curriculum for schools.

As funding is freed from teaching expenditure, this funding can be allocated to other productive activities such as:

1. Improving curriculum design and assessment.

   As students start becoming more expert in learning, they will become better at evaluating the quality of educational materials. Quizzes play an important formative role, informing learners where they need to study. Learning also occurs during a quiz, as the mind recalls and applies their knowledge. Currently, students dislike quizzes as they force study and create anxiety. Teachers themselves avoid them as writing good quizzes is itself a demanding instructional skill. However, as students start understanding the high value of quizzes, they will start demanding more.

2. Move students from independence to interdependence and service.

   Independent learning is not the culmination. Covey (1989, 2013) proposed a four-stage model of human development that can be characterised as dependence -> independence -> interdependence -> service, which has direct correlates with learning stages. The concept of interdependent learning is already well established, with Bandura's (1986) model of social learning, and current pedagogic models for group and team work.

   The concept of service as a definitive life stage is less well recognised. It aligns with Maslow's (Koltko-Rivera, 2006; Maslow, 1954; 1971) concept of self-transcendence as the final stage in the hierarchy of needs. Universities are moving beyond their traditional model with its two outputs of Teaching and Research, to adding a third one called "Engagement" – reaching out and serving the wider community. A small but growing movement is Ashoka U – an expanding consortium of universities committed to developing social entrepreneurship among its students. The next point discusses integrating service into the curriculum.

3. Replacing teaching with other curriculum delivery mechanisms that better utilise the students as a resource – e.g. engaging the students in community outreach programs, work based learning and research[21,22].

University students are a major underutilised national resource. At present, we consider productive work and learning as independent activities that cannot be done simultaneously. However, once we recognise that learning needs repetition and that even competent workers do make mistakes, we are more amenable to implementing work-learning environments involving repetition with high levels of supervision. The issue is that designing and operating suitable work-learning environments takes a significant amount of skill and energy.

Such a work-learning environment exists in research. Senior professors manage research teams with experienced researchers as well as research students working together. One also sees such a structure in the medical specialities, with work-learning hierarchy of specialists, registrars and junior doctors.

There are opportunities in many fields. Public health campaigns needing home visits

[21] To ensure viability and cost effectiveness, such programs need to be designed as repeatable processes rather than one-off projects that need substantial development for every student batch.

[22] A good example is students become office bearers of professional associations related to their study (Legaspi, 2017).

or child health checks could be performed by pairs of students, or even a senior student and a junior student, with robust quality systems in place. But, it would need academic staff with the capacity and willingness to work routinely in the field.

4. Expand the university's focus on tertiary education beyond that of current students – e.g., the continuing development of former students and tertiary education for the wider community.

   Trow (Marginson, 2017; Trow, 2005) popularised the concept of increasing participation in university education: from elite to mass to universal. Techniques such as MOOCs and using students to teach; develop course material; assessment items or wikis are techniques that can reduce cost of higher education available. But they need leadership and a commitment to ensuring continuity.

5. Expand university research of the human sciences, particularly the science of learning.

   The human sciences are rapidly expanding. Applying this new knowledge and skills presents a significant opportunity to intractable, wicked social problems which have withstood previous efforts at resolution. Universities, which bring together a broad range of disciplines under (figuratively) one roof, provide a unique opportunity for integrating disciplines.

   ASEAN universities are well placed to undertake such research. Research in these disciplines often does not need expensive laboratories with specialist equipment. Or, teams can form with members from multiple universities, even across borders, each university contributing different scholarly expertise and resources.

   One promising area of research on the Science of Learning is biofeedback. Electronic equipment that detects minute changes in the body is becoming cheaper and more accurate. Providing real-time feedback to students on neurobiological changes allows them to develop the skills of being consciously able to control these changes. For example, children often have difficulty paying attention. Children with significant difficulty in paying attention may be diagnosed as having Attention-Deficit Hyperactivity Disorder (ADHD). Children have been successfully trained at school to improve their behaviour by providing biofeedback using an electroencephalogram to monitor changes in brain patterns (Steiner et.al., 2014). Other non-invasive biofeedback instruments could include cameras to detect eye movement (Frutos-Pascual & Garcia-Zapirain, 2015) or monitors that detect changes to heartbeats that signal stress (Prinsloo et.al, 2011)[23].

These five activities discussed above are not separate but rather feed into and support one another as an integrated whole – the sum of which is far greater than the parts. They integrate student learning into the two other major functions of universities, research and community engagement.

Critical Review

A principal strength of science in comparison with other bodies of knowledge such as religion is its scepticism (Harari, 2014). Science is built on the premise that its body of knowledge is incomplete and prone to error. It is the duty of scientists – both authors and readers - to apply scepticism.

This paper consolidates and conceptualises research and theory from scholars in multiple disciplines. Research and theory that are and will continue to evolve and regularly be corrected. The human brain automatically seeks patterns – a sense-making reflex: ancient seers looked at the stars and saw constellations – their gods. The task of modern scholars is akin to the ancient Asian parable of the king who led blind men, each to a different part of an elephant and asked them to describe the animal. The man at the head perceived a jar, the one at the ear a winnowing basket….. Disagreeing, they fell to blows ("Udana: Exclamations," 2012, p. 6:4). Modern scholars overcome this blindness through conferences, with multi-disciplinary research teams, and above all by joining together to form universities.

This paper goes even further. It seeks to predict the future. And not simply predict an invariant outcome but advocates steps for a preferred outcome. Steps that go beyond the role of traditional objective science, to an

[23] Often, equipment such as EEGs, tracking cameras and pulse monitors are mass-produced by local (ASEAN) industry. Universities may be able to set up partnerships with local industry to fine-tune equipment (such as apps that provide connectivity with mobile phones).

intensely subjective, value ridden activity. But that is the nature of Futures Studies (Bell, 1997, 2003, p. 5): “to demystify the future, to make their methods explicit, to be systematic and rational, to base their observation on the empirical observation of reality when relevant, and to test rigorously the plausibility of their logic in open discussion and intellectual debate”.

This paper is a synthesis. It identifies seminal basic research from multiple disciplines, and via inductive reasoning presents them as a coherent body of knowledge that can be taught to achieve a society of independent learners capable of fuelling a social revolution comparable to the industrial revolution. The paper also cites evidence that this research is being popularised by scholars and consumed by a thirsty public. The revolution is underway. What the paper does not do, is beyond its scope, is to quantify the status of the revolution, or what would constitute a critical mass.

Conclusion

This paper began by positing a scientific revolution in the human sciences, and detailed four such paradigm shifts in our understanding of human learning. This revolution also extends to our understanding of society and its structures. To design and implement this vision we need to apply our new understanding of society and its structures.

The revolution is by no means over. It is continuing. Some may argue that it is better to wait till the science is absolute, for the path to be even clearer and more definitive than it is now. But science is always progressing, and there is likely to be no definitive end. Rather, it is incumbent on us to do what we can, using our best endeavours and best understanding. Education is an applied science, and applied scientists have to leave the laboratory, develop practical solutions for today with incomplete science[24]. Practical solutions that reduce costs. Universities are tasked with allocating resources wisely to further this understanding, communicating this understanding to the wider community and applying it to their own operations.

[24] Science will never be complete. Even Newtons Laws, were corrected three centuries later by Einsteinian relativity.

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