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# Sustaining Competencies and Employability: A Fishbone Model for Engineering Education to Fit the Processes of Life

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## ABSTRACT

Just as breakthroughs in the physical sciences fueled the industrial revolution, we are now in the early stages of a social revolution fueled by breakthroughs in the human sciences. This paper builds on a paper presented at SEAAIR 2017 that discussed new understandings from the Science of Learning. The current paper combines emergent knowledge from neurobiology with social and cultural timelines to propose a nuanced and situated "*fishbone*" model of human life processes. From conception to terminal illness, the changes in different parts of the brain are not uniform. Different parts of the brain perform different functions that, when scaffolded, deliver higher-level skills. For example, understanding tonal languages require a strong sense of differences in pitch, a skill most easily developed in early childhood. The paper then explores the implications of this model for delivering sustaining competencies and employability to our citizens. Furthermore, education is currently designed as a *push method* – education is largely pushed out in early life, to meet the demands of a whole lifetime. The paper proposes that to be sustained, the education industry needs to be re-engineered to a *pull approach*. Advances in the Science of Learning allow young citizens to be effectively taught to be independent learners. Independent learners can pull in (to learn independently) the knowledge and skills *Just In Time (JIT)* to be relevant to their life stage. ASEAN @ 50, led by its higher education sector, can deliver sustaining competencies and employability to its citizens.

**Keywords:** Competencies, Employability, Science of Learning, Sensitive periods, Independent learning

## Introduction

The technological marvels all around us that we now take for granted can be traced to industrial revolutions that were sparked by paradigmatic advances in the physical sciences (Kuhn, 1962, 1970). We are now seeing similar paradigmatic advances in the human sciences that are capable of social revolutions. In last year's SEAAIR conference, the principal author presented a paper that proposed that the Science of Learning has matured to a point that everyone can be taught to be independent learners (Somasundaram, 2017). That paper described specific crucial discoveries from the Science of Learning and discussed their implications for higher education. A subsequently invited paper for the *ASEAN Journal of Education* further developed the theme of both the discoveries from the Science of Learning and the implications for early, school, and higher education (Somasundaram, in press). The discoveries presented in the above papers are briefly described in the next section, "Background".

The theme for this conference is "Sustaining Student Competencies and Employability". The theme requires us to plan and propose the future. To be sustaining, policies need to be both efficient (at least cost, and ideally using renewable resources) and effective (provide the necessary skills and competencies for successful wellbeing). The third section, "Methodology", discusses the nature of this inquiry: the types of scholarships that the paper engages. The section also describes two techniques from engineering supply chain management, "*Push/Pull*" and "*Just in Time"*, which when coupled with a citizenry of independent learners can deliver sustainable education.

The fourth section, "Stages of Life model", develops a model for the delivery of education. It draws from and integrates two different sources: firstly, our understanding of neurobiological changes during life; and secondly, the competencies needed for well-being at different stages of life.

As this conference is for members from universities, the fifth section briefly discusses the implications for universities. The final, sixth section "Conclusions' summarises the opportunities suggested by this paper for the ASEAN community @ its fiftieth anniversary.

## Background

A paper (Somasundaram, 2017) at last year's SEAAIR conference and a subsequently invited paper (Somasundaram, in press) for the *ASEAN Journal of Education* explored and developed five core concepts from the Science of Learning that, taken together, provide the basis for creating a curriculum for teaching students to be independent learners. Once all students become independent learners, then the role of subsequent educators changes dramatically: they can devote far less time to teaching, and more resources become available for other functions such as instructional design and research. The five concepts are briefly summarised below. However, readers should refer to the original articles for a more detailed, nuanced understanding and references and further sources.

***Neuroplasticity, cognitive load theory, chunking, and sleep memory formation are four critical discoveries that, blended, describe how learning takes place.***

Neuroplasticity refers to the way that learning occurs. The ends of nerve cells (synapses) grow when messages are repeatedly transmitted along with them (and prune when there are fewer messages). Learning is a physical strengthening of some neural pathways over others. Cognitive load theory describes the limited ability of the part of the mind involved in concentrated thinking to hold many different bits of information simultaneously. We cannot understand something when it consists of too many different bits of information. On the other hand, when we repeatedly connect different bits of information, then the mind chunks them into one larger bit of information. Once bits of information is chunked, then they can fit into working memory. We can handle complex information in working memory when the many bits have been chunked into a few larger bits. For example, small children, when learning to read, need to focus on every letter and how it forms a word. But over time they can grasp the whole word instantly, and therefore can easily understand sentences[2].

The importance of sleep is only now being unraveled. Two periods appear critical. A particular type of brain activity known as spindle waves transfers what is learned during the day into deeper, long-term memory. Spindle sleep both forms long-term memory and clears up memory spaces to absorb a new day's learning. Rapid Eye movement (REM) sleep is associated with brain waves that appear random, like static noise. REM sleep strips strong negative emotions from memories, reducing anxieties. Furthermore, during REM sleep new and older memories fire together, suggesting relationships that may not have been explicitly taught.

This basic scientific understanding of how the brain functions have important practical implications. Learning occurs through repetition and recall, spaced over days so that sleep enables deep learning. Students should move onto more difficult material only after simpler material has been sufficiently chunked.

***The theory of flow shows how to make learning enjoyable***

Mihaly Csikszentmihalyi (2014a, 2014b) developed the theory of flow to describe the state of focused concentration, almost like a trance, that athletes and others immersed in an activity fall into. This concentration happens when the activity on which the individual is focused is neither too hard nor too easy. When the material is too hard, then the unpleasantness of error overwhelms the participant, and she or he breaks concentration. On the other hand, when the activity is always successful, then the repeated triggering of the reward circuits causes satiety, a drop in pleasure, and boredom.

Studies of experts, individuals in the sport, and other professions, who have moved beyond mere competence to world-class performance provide more nuanced insights. Their training programs,

[2] In teaching young children to read, phonics must precede whole word approaches.

called "deliberate practice", are not simply long, but also embrace some degree of unpleasantness – they deliberately pay attention to and practice elements in which they are weak.

***There are two distinct modes of thinking***

Thinking can be divided into two distinct categories. Focused, concentrated thinking is distinguished by strong neural activity predominantly in the front of the brain (the task-positive network). Another type of thought, which could be called "*diffused*", is characterized by a dampening in the task-positive network, and greater activity in other parts of the brain called "the default mode network". "Daydreaming", "intuition" and "subconscious thoughts" are terms associated with the diffuse mode of thinking.

While western philosophy and culture have tended to idealize focused thinking and consider diffuse thinking idle and wasteful, a more balanced perspective is more useful. While focused thinking is necessary for learning, and usually results in more accurate and reliable results, we generally use diffuse thinking most of the time. Diffuse thinking is associated with creativity and may be more effective for solving complex problems with no easy solutions. Focused thinking, by its nature, tends to block out alternatives.

***Cognition is integral with sensory/motor, emotional and social operations***

The human brain works in an integrated manner. We like to picture cognition sitting like a puppeteer pulling the strings on a human body, with emotional, social, and sensory-motor operations as separate, independent activities. In reality, these different operations feed into and off one another.

Our education systems have tended to privilege cognition and neglect the other operations of the brain. For example, reading requires the movement of the eye in jumps known as "saccades" and a spoken vocabulary developed by listening and speaking. Concentration and motivation require the development of emotional skills. Employers are increasingly becoming aware of the importance of emotional and social skills and critiquing education for not developing these skills in students.

***Neurobiological circuitry matures in a predictable pattern of sensitive periods.***

Historically, the concept of the brain as maturing linearly until adulthood, and then remaining constant, has been common. While some educators such as Piaget (1972) have, through observation, proposed several stages of development, we are starting to have a far more nuanced and sophisticated understanding of how different parts of the brain change with age. Some stages appear to be particularly important for the development of certain skills. If a child does not develop a particular skill during a sensitive period, then it is much harder to develop that skill in later life. For example, tonal languages and singing require the ability to sense pitch, a skill that is hard to learn after the age of five.

The model proposed in this paper, and described in section four, combines changes in our neurobiological circuitry with the changing roles and expectations of society during different life stages.

## Methodology

Ernst Boyer, in his influential book *Scholarship, reconsidered: Priorities of the professoriate* (1990), said that academics had four scholarly tasks: (1) the scholarship of discovery; (2) the scholarship of integration; (3) the scholarship of application; and (4) the scholarship of teaching. By discovery, he meant traditional research – the discovery of new knowledge from within a single discipline. By integration, he meant the creation of new knowledge and insights by fusing knowledge from two or more disciplines, similar to the more recent terms "multidisciplinary" and "transdisciplinary" research. By application, he meant the application of fundamental science to solve real-world problems, similar to our concept of applied sciences and what in the health sector is now called "translational research". Education is an applied science. By the scholarship of teaching, he meant teaching in a scholarly manner – teaching that embraces and applies the frontiers of knowledge to the education of students.

This paper is a combination of the scholarships of integration and application. It integrates knowledge from several disciplines in the fundamental sciences? and applies it to transform education.

This paper applies the discipline of futures studies (Bell, 1997, 2003) - the discipline that seeks to forecast the future. The prediction is based on an environmental scan that identified specific discoveries and trends. The goal of futures studies is not only to forecast the future but also to influence it – to create a preferred future.

Life is a process from conception to death, with discrete stages. The individual undergoes neurobiological changes during this period and also needs specific skills and competencies to thrive at every stage. Engineering, like education, is an applied science – the application of the pure sciences for practical purposes. This paper applies knowledge from the multidisciplinary Science of Learning and draws on concepts from the engineering discipline of industrial supply chain management for the practical purpose of creating sustainable competencies and skills during the processes of human life.

From this perspective, the methodology deployed in this paper is conceptual, mobilizing selected concepts to explicate a speculative and potentially provocative argument to endorse the value of a particular model of education derived from current learnings from the scholarship of engineering. Rather than drawing on the constructs and data collection instruments associated with empirical research, the rigor of this approach depends on the perceived coherence, relevance, and utility of the model developed here to address enduringly significant, real-life

debates and issues. Moreover, this approach embraces an abductive approach to analysis, whereby:

Abduction occurs when we encounter observations that do not neatly fit existing theories and we find ourselves speculating about what the data plausibly could be a case of. Abduction thus refers to a creative inferential process aimed at producing new hypotheses and theories based on surprising research evidence. Abduction produces a new hypothesis for which we then need to gather more observations. (Tavory & Timmermans, 2014, p. 5)

***Push-Pull***

The term "push-pull" is derived from the engineering discipline of industrial supply chain management (Janvier-James, 2012). It helps us to understand two contrasting ways of providing goods and services applicable to supply chains when an end product requires the manufacture of goods in different stages. In push markets, suppliers maintain control, pushing goods and services onto the market. They decide quantity and quality. In pull markets, consumers seek the goods and services that they want, in both quantity and quality, which manufacturers produce. Push markets favor suppliers since they have greater control of what goods they produce and when they produce those goods. Goods can often be cheaper since they can design manufacture to achieve economies of scale. Education represents a push model, with education being delivered to students at the convenience of the education providers.

If on the other hand student can be independent learners, then they will be able to achieve a pull system, pulling in the learning of their choice rather than being dependent on the education system to supply it at the education system's convenience.

***Just in time***

The term "just in time (JIT)" is also derived from supply chain management, and is associated with pull systems (Sugimori, Kusunoki, Cho, & Uchikawa, 1977). As the term implies, JIT refers to goods being manufactured only just before they are needed. In manufacturing, JIT relationships require tight coordination, since miscommunication will result in a disruption of production flow. The benefits of JIT are that it reduces capital being tied up in unnecessary stock and that it minimizes obsolescence and waste. A JIT approach in education would mean that students will not have to learn things that they never use, and will not forget what they need to know, and that, in a world where scientific knowledge changes every year, what they learn will be up-to-date.

***Limitations of this paper***

Our conceptualization of the world is beautifully described by the Asian parable of the king who called his blind men to describe an elephant ("Udana: Exclamations", 2012). The blind man feeling the ear describes a winnowing basket, the blind man at the head a jar, and the tusk felt like a ploughshare…. It is the task of the integrationist to draw these disparate knowings and to create a model: "*All models are wrong, but some are useful*" (Box, 1979, p. 2). Science is never

complete, and in disciplines such as neuroscience, we still have much to learn about the biophysical nature of thinking and learning. It falls on the reader to judge this paper's usefulness, and whether it presents a practical way forward. Does it provide you, the reader, with insights that you can use in playing your part in improving society?

## The Stages of Life model

This model is an integration of two elements: (1) neurobiological changes at different stages of life that impact learning; and (2) the demands of society and life – what a person needs to know at different stages of life[3].

***Neurobiological changes***

i. Foetus. While massive conditions that result in easily noticeable damage such as spinal tu be defects are well known, only recently has more subtle damage such as Attention Deficit Hyperactivity Disorder owing to maternal stress (Ronald, Pennell, & Whitehouse, 2011) been identified. This subtler damage not only disadvantages the individual child bu t can also have a significant impact on classroom management and stress levels, impactin g the learning of all peer students.

ii. Infant. The brain continues to grow rapidly after birth, and the infant starts interacting wit h the outside world. Sensory-motor networks that are the foundations of human communi cation and movement are being formed at this stage. Safety and the absence of toxic stres s continue to be critical. The infant also seeks to bond with the mother and other caregive rs, and this bonding is important as the foundation for later social and emotional intellige nce. The classic communication cycle between the infant and caregiver, where one initiat es an action – such as a smile or a noise – and the other response, sometimes called "a ser ve-and-return cycle" (Center on the Developing Child at Harvard University, 2014), is an important training tool.

    - Learning is a scaffolded activity. Timely foundational learning ensures timely conti nued development. For example, infants who are routinely massaged and permitted free movement to learn to crawl earlier. Early crawling ensures that the child has a greater ability to explore the environment and to learn novel skills. Babies learn to make speech-like sounds that proceed to words. Verbal interactions with caregivers increase vocabulary. Children with a greater spoken vocabulary when they enter sch ool learn to read faster.

iii. Toddler. The period called "the terrible twos and threes" marks a period of increasing ind ependence (ability to walk) with the development of the awareness of self and greater em otional development but still low self-control. Perhaps most concerning to parents is the emergence of lying and the ability to conceal the lie elaborately. The child's increased me

[3] The paper describes the stages in life in a typical Western society.

ntal and physical abilities make them more powerful, but they are yet to be shaped and co nstrained by cultural and social norms (Evans & Lee, 2013).

iv. Puberty. The release of pubertal hormones begins another period of high neuroplasticity. Changing hormone levels amplify emotions to which the teenager is not used accustomed . Importantly, the maturation of different parts of the brain is not uniform, with regions i mportant for executive control maturing later, and teenagers are less able to evaluate risks and exercise control.

v. Adult. Neural development reaches a peak and then starts to deteriorate slowly. Like the physical body, the rate of mental deterioration depends on a variety of factors, including ( mental) exercise. The deterioration is initially very slow and not noticeable. Furthermore, while the speed of thinking and learning may be slower, this is more than compensated fo r by the increase in knowledge and skills that occur. It is therefore crucial that adults do n ot stop learning.

vi. Childbirth. The hormones triggered by pregnancy cause changes to brain areas responsibl e for social and emotional skills. These changes are evolutionary tactics to improve mater nal bonding and childcare skills (Hoekzema et al., 2017); complementary changes in men have not been detected.

vii. Multi-system failure. The human mind is a complex, evolved system. Evolved systems sh ow a characteristic called "graceful degradation": unlike many machines, in which the fai lure of a single bolt may cause the machine to stop working, evolved systems tend to hav e sub-systems that compensate, such as nerve damage in one ear being compensated for b y the other ear or by an increasing ability to lip-read. However, with aging, other systems that compensate may find the load too much and themselves fail more rapidly. While hist orically such periods before death have been quite short, modern medicine has extended t his period. The individual becomes more and more dependent on others for daily tasks.

viii. Daily and seasonal rhythms. We also have a daily rhythm that is often poorly exploited. As was discussed in section 2.1, sleep plays an important part in learning. Sleep needs ch ange during different life stages. Furthermore, individuals have different sleep patterns, falling into three roughly equal groups. Larks are early morning risers, owls prefer a later sleep cycle and 'in-betweeners' fall into the middle. When individuals are awake, alertnes s rises to a peak after awakening then drops (with an afternoon siesta in some cultures), th en rises again before tapering down for the sleep cycle.

While many religions incorporate a lunar cycle, evidence for human neurobiological changes is weak. There is some evidence for an annual cycle (such as the seasonal affective disorder), perhaps more pronounced when living in areas affected by daylight differences.

Understanding these patterns is valuable for both education and societal design. For example, with puberty, teenagers' body clocks shift backward, turning them into owls. This means that

morning learning is less efficacious. Furthermore, forcing them to wake up before they have had sufficient spindle and REM sleep to digest the previous day's learning is not productive. Studies in the United States have shown that delaying school start times for teenagers has a significant effect on road crashes for this cohort (in one study, the reduction was 70%) (Walker, 2017).

***Social, cultural, and job transitions***

i. Early childhood. Infants and young children are voracious independent learners. They lear n to walk and talk, extremely complex skills, with focus and determination, virtually by th emselves. At birth, they are dependent on their caregivers for the essentials of life. Exte nded families, social groups, and pre-school extend the child's experience and gradually a cclimatize the child to the outside world and prepare her or him for school.

ii. Primary school. The primary school typically represents a major environmental change. W hile some children are ready and thrive with the move, for others it is stressful and unpleas ant. The change is made based on societal rules, with less regard to the individual child's l evels of maturation in sensory-motor, cognitive, emotional, and social skills.

iii. Secondary school. The secondary school represents another important transition. Again, if children are not ready for the transition, they will not thrive.

iv. Pair bonding and marriage. With puberty comes increasing interest in mating activities. If good emotional and social skills have not been established by this age, then individuals are more likely to accede to escalating inappropriate behavior leading to domestic abuse. Dom estic abuse is often intergenerational, and education about what constitutes acceptable beh avior and how to maintain safety before pair bonding commences is optimal.

v. Post-secondary education. The transition from school to trade and university education rep resents another major shift, requiring different competencies. Often students will also leav e home at this point. They face greater freedoms as well as responsibilities.

vi. First job. The transition to the initial workplace requires individuals to develop job-specifi c technical and social skills. Even issues such as neatness and punctuality may need to be i mproved. Students transitioning to the workplace also suddenly have significantly greater income, and sound money-management and savings skills need to be established.

vii. Parenthood. The birth of children creates significant stresses as well as the need for critical parenting skills. State interventions during this period, to ensure adequate skills and suppo rt, may be necessary to break cycles of intergenerational disadvantage.

viii. Job changes. The days when an individual started a post-schooling job and held the same j ob till retirement, are long over. Transitions between jobs are now a fact of life. Furthermore, as vocations radically change or disappear, transitions are often between jobs that require very different skill-sets. Furthermore, where the transition is involuntary, the i ndividual may need motivational skills to make a successful transition. Two important poi

nts regarding (workplace) transitions made by Bridges (2009) are :(1) The change in envir onment is typically rapid, while the learning of the skills necessary for the new environme nt takes time; (2) Individuals may often have negative emotions about change, and they ty pically need to go through several stages to achieve the strong positive motivation that rea dies them to thrive in the new environment.

ix. Retirement. Work fills up a person's time and is often an important if not a primary activit y that provides purpose and meaning in a person's life. Retirement can therefore create a major vacuum that, unless transitioned successfully, can lead to depression and decline.

x. Spousal death. Spousal relationships represent by far the most important social bond. Not only is the breaking of the bond traumatic, but also the individual may not have the skills or inclination to create other bonds to support themselves. Spousal skills often complemen t each other, and the loss of a spouse often creates a loss of life skills, such as cooking or fi nancial management.

xi. Assisted living/nursing home. As individuals age, they lose both the physical and the ment al skills to function independently. This assistance may be provided by either trained profe ssionals or family members, and skills are required, by both the individual and the person assisting, to ensure that the transition is smooth.

xii. Most religions posit an after-life, and much of religious education is geared towards that tr ansition. However, this is beyond the scope of this paper.

### *A Fishbone Model*

An integration of neurobiological changes at different stages of life that impact learning, the demands of society, and life – what a person needs to know at different stages of life – is shown in Figure 1 below.

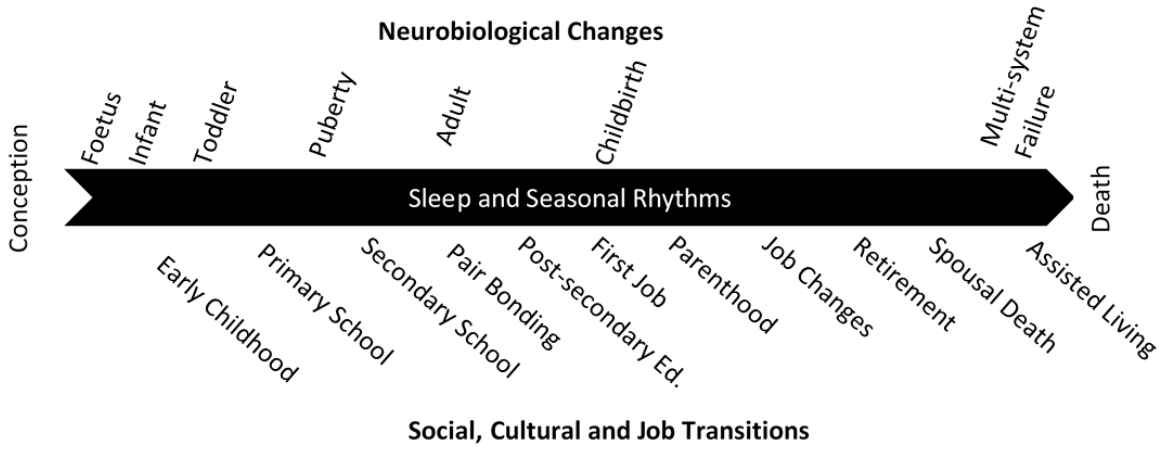


Figure 1: Integration of neurobiological changes with social, cultural, and job transitions

## Implications for universities

Universities have three roles to play in this transformation:

### *Change Agent*

Universities have both the responsibility and the opportunity to lead the revolution that the human sciences are delivering. Not only is much of the new science being uncovered by universities, but universities are also a crucible of the different disciplines and can develop integrated solutions. But, to do this, universities need to be better at breaking out of the silos that academic departments form, and to develop the skills of applying the science to the real world.

A central requirement of this model is that all citizens (school leavers) are competent, independent learners. Changing the school curriculum to ensure that all students become independent learners is an activity that universities can greatly influence.

### *Delivering Education to the New Model*

The model presented in this paper disrupts current structures in two major ways. Firstly, the public services of health, education, and welfare are structured as independent arms of government. This model proposes a more integrated model in several respects, with certain (but not all) elements of the services needing to be delivered in a far more integrated fashion. Secondly, education is broadly delivered in two ways: schooling and post-schooling. This model proposes a far broader scope and responsibility for education: from conception to death.

### *Further Research*

The industrial revolutions, which commenced over two centuries ago, are continuing, and arguably even accelerating as the progress of the physical sciences. There is still much to unravel in the human sciences, and the private sector, while often leading in their application, is unlikely to invest in the rigorous methods that science demands. It, therefore, falls largely on public sector and university researchers to advance the human sciences.

### *Implications for Higher Education*

The argument being propounded here has three important implications for contemporary higher education institutions. Firstly, the university's public service mission of contributing substantially and sustainably to the common good (Nixon, 2012) can be harnessed and strengthened by embracing wholeheartedly the ideas outlined here by ensuring that curriculum, teaching, and assessment policies and practices are aligned directly with a focus on facilitating the growth of independent, lifelong learners with multiple and malleable competencies for all aspects of the current world. Secondly, the research agenda of universities can be extended and enriched by a more explicit consideration of Boyer's (1990) four scholarships articulated above, and in particular of how universities can foster increased linkages among these scholarships. Thirdly, these requirements for greater alignment and increased linkages reinforce the need for universities to be outward-facing concerning their diverse constituencies and their varied

stakeholders, thereby highlighting their broader social and community responsibilities (Zhang, Liu, & Zhang, 2018).

## Conclusion

The theme of this conference – "*ASEAN@50: Sustaining student competencies and employability"* - demands that we as scholars gather ourselves, our knowledge, and our competencies to forecast and shape our preferred futures.

This paper proposes one such potential future of an educated society: one where every citizen is taught the science of becoming an independent learner, and where higher education institutions design neurobiologically appropriate courses to meet the cultural and work-related needs of the individual. These courses can be delivered cheaply/sustainably through methods such as Massive Open Online Courses (MOOCS). Individuals can then *pull* the necessary learning *just in time*, thereby providing economic and sustainable competencies for a post-50 ASEAN citizenry.

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