Chapter 7
Is Calculus Relevant to Survival? Managing the Evolutionary Novelty of Modern Education

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Lay Summary Efficient and effective education is important not simply for producing the next generation of scientists, engineers, doctors, or skilled laborers, but for issues of child health, public health, and health education. Many approaches and theories contribute to education policies; however, an often overlooked dynamic is incorporating human evolutionary history into education practice, especially considering the historical novelty of formal education in human life. Evolution has physiologically, cognitively, and socially shaped human children and adults, making it an important consideration for any large-scale education endeavor. Through consideration of evolutionary and developmental psychology, we propose that education practices can become more child-centered by considering specific traits in children selected for by evolution.

7.1 Introduction

7.1.1 The Advent of Standardized Education

For most of human history, and for all of human prehistory, children learned the skills necessary to be competent adults in their society "in the context" of daily life.

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As such, the best available proxy of early human life is modern hunter-gatherers. We must take care to acknowledge that current research cannot assume perfect correspondence between modern groups and those living across evolutionary time, but the opportunity for comparison is relevant and advantageous [1]. Hunter-gatherer children spend most of their days freely playing with other children in mixed-age groups, learning practical skills from their older peers, and occasionally learning important skills by watching and interacting with their parents or other adults. Modern hunter-gatherer adults rarely directly instruct children in any skill, and it is likely that this was also true for our ancestors [2–4].

With the advent of agriculture and a more sedentary lifestyle, children continued to learn necessary life skills by performing them, often in the company of older and more accomplished individuals, and they often practiced such skills in their play. The need to be literate (and later numerate) changed not only what children needed to learn but also how they learned it. Although writing dates back nearly 6000 years, for millennia only the elite (priests, members of the ruling class, some merchants) were literate, and such advanced knowledge was typically passed on to others via tutoring. Until the invention of the printing press in the 1400s, the written word could not be mass produced (and thus mass consumed). Cultural changes accompanying the ability to economically print books made reading an important adult skill, one that differentiated illiterate children from literate adults [5]. Subsequently, learning shifted to schooling, which is done "out of context," with children having to master tasks that have no immediate relevance for their daily lives.

In contrast to children from traditional societies, modern technological skills are usually learned to meet modern cultural needs, not to solve any pressing problem of survival, making this style of learning an evolutionary novelty. Modern children must also learn these skills and related information whether they are interested and motivated for such learning or not. Although some children will learn to read and calculate on their own via discovery learning, many will not, and direct instruction and tedious practice, to some degree, are inevitable.

Most developed nations see having an educated populace as the backbone of a successful society, and, around the world, nations vie to develop curricula that will produce intelligent and productive citizens. Although America currently leads the world in worker productivity and scientific accomplishments, the achievement gap between children from middle-class versus lower-income homes is substantial, and parents, educators, and government officials have focused their attention on improving American children's academic accomplishments while reducing the learning gap between the "haves" and "have nots." As a result, the USA, as well as other developed countries, has increased its emphasis of academic learning, often at the expense of other non-tested subjects, such as art, music, and physical education, and activities such as recess [6]. The important skills of mathematics and reading are increasingly stressed, as required by the 2002 Federal No Child Left Behind Act, which mandated assessment of progress in these core subjects for children in the grades 3–8.

Although there is substantial controversy on the success of No Child Left Behind on children's academic performance, some gains are found at some ages for some abilities, but not at other ages for other abilities [7–9]. One consequence of No

Child Left Behind is the use of standardized assessments as a yardstick for a school's (or classroom's) progress, often with monetary rewards and punishments linked to children's scores on the tests. However, even if we grant the gains in academic abilities, there is a potential downside. Academic subjects not explicitly assessed may not receive the same classroom attention as the "tested" subjects, with the majority of resources devoted to rigorous instruction on these tested subjects. Because of these performance demands, school has increasingly become a high-stress environment, for both children and teachers. According to developmental psychologist William Crain [10],

> Historically, children seem to have never liked school very much. It has always taken a toll on the natural curiosity and enthusiasm for learning with which children began life. But today, as the standards movement rolls on, the pressure on children is becoming quite oppressive

(p. 10) Crain further writes

> … [W]e are, in effect, stunting their growth, and future research may show that the effects show up in increased depression, suicidal ideation, restlessness, and other symptoms of unfulfilled lives" (p. 6).

These concerns were echoed a decade later by Gray [11], among others, who posits that contemporary education practices have produced a generation of highly stressed, unenthusiastic students, who are ill-prepared for the challenges that a changing economy presents. The push by modern schools for early and invariant achievement may be mismatched with the often slow-paced cognitive and social development of human children. Gray [11], among others [12–15], suggests that modern educational practices can be made more effective by considering the environment in which learning had taken place over evolutionary history.

7.1.2 Evolutionary Educational Psychology

David Geary [13, 16, 17], a vocal advocate of an evolutionarily informed approach to education, proposed that humans evolved intuitive cognitive systems for managing their physical, biologic, and social worlds (folk physics, folk biology, and folk psychology) that develop over childhood (see Fig. 7.1). Geary referred to these as biologically primary abilities. They are universal and develop in a species-typical pattern given a species-typical environment, and children are intrinsically motivated to engage in them. Language is perhaps the prototypical example of a biologically primary ability; specific neurological architecture is responsible for its functioning and, with appropriate input, is a universal human trait. These are contrasted with biologically secondary abilities, which do not have an evolutionary history but rather are based on biologically primary abilities. Reading is a clear example of a biologically secondary ability; based on language abilities, it is a non-essential cultural extension of a primary domain. Biologically secondary abilities could just as easily be called "culturally primary abilities," as

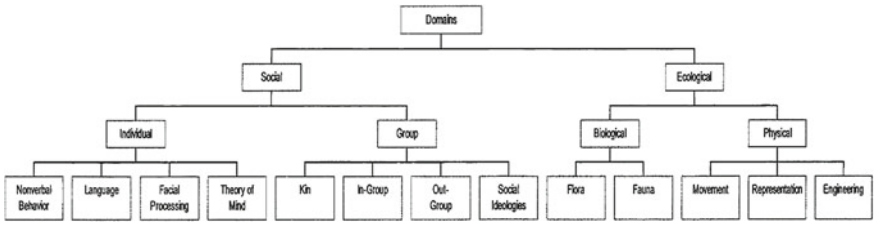

Fig. 7.1 Proposed domains of mind. From Ref. [51]. Reprinted with permission

they are invented by each culture to deal with ecological demands. When these ecological demands are similar among different cultures (e.g., the need for communication between group members), the produced ability is likely to be similar. However, when demands vary with culture or ecology, the resulting abilities are also likely to vary. Thus, unlike biologically primary abilities, biologically secondary abilities are not universal and children are not necessarily intrinsically motivated to achieve proficiency. As such, biologically secondary abilities are most often those that require formal teaching and education. For example, the use of language (speaking and listening; a primary ability) is not explicitly taught in school to the same degree as reading and writing (secondary abilities).

Geary proposed that humans' inventions of new technologies often result in gaps between intuitive folk knowledge (acquired via biologically primary abilities) and the skills needed to be successful in modern societies (acquired via biologically secondary abilities). Based on these premises, Geary presented six principles of evolutionary educational psychology, and these are displayed in Table 7.1. As you can see, Geary argues that the role of schools is to fill the gap between folk knowledge and needed technological skills. Moreover, because children are not inherently motivated to exercise biologically secondary skills, direct instruction is often needed. Yet, children's acquisition of a biologically secondary skill can be facilitated if the content is related to their biologically primary interests. For example, with respect to reading, Geary [16: 28] states:

> The motivation to read … is probably driven by the content of what is being read rather than by the process itself. In fact, the content of many stories and other secondary activities (e.g., video games, television) might reflect evolutionary-relevant themes that motivate engagement in these activities (e.g., social relationships, competition…).

With respect to reading, this may be especially important for boys, who, compared to girls, have lower levels of reading comprehension for low-interest stories [18]. As a result of less motivation for acquiring biologically secondary skills, explicit instruction (as opposed to "discovery learning") is typically necessary for many children to acquire these skills.

Therefore, an evolutionarily informed theory of education must translate three major themes into applicable pedagogy: human evolutionary history, modern technological necessities, and practices for best bridging the gaps between

Table 7.1 Principles of evolutionary educational psychology. Adapted from Ref. [13]

Principles of evolutionary educational psychology
1. Biologically secondary abilities associated with scientific, technological, and academic advances emerged from the biologically primary abilities associated with folk physics, folk biology, and folk psychology. As a society's knowledge increases, the gap between folk knowledge and the skills necessary to acquire the technological skills of society widens
2. Schools emerged in societies to fill the gap between folk knowledge and needed technological skills
3. The purpose of schools is to organize the activities of children, so they can acquire the biologically secondary abilities that close the gap between folk knowledge and the occupational and social demands of their society
4. Biologically secondary abilities are built from biologically primary abilities and components of general intelligence and evolved to deal with environmental variation and novelty
5. Children are inherently motivated to engage in activities that promote their folk knowledge, but this sometimes conflicts with the need to engage in activity that will promote secondary learning (e.g., reading), because children are not inherently motivated to engage in biologically secondary abilities
6. There is a need for direct instruction for children to learn most biologically secondary abilities

children's intuitive capabilities and those required by their ecology. The remainder of this chapter will evaluate the merits of such a perspective through specific examples.

7.2 Research Findings

7.2.1 Educating Homo Ludens

In his 1944 book, *Homo Ludens* (Playing Man), Johan Huizinga [19] argued that play serves an important function throughout the human life span, pointing out that humans are the only species who plays for the sake of playing into adulthood. In adulthood, we think of play as recreational and socially affiliative; however, childhood play is, in many respects, work. When children engage in symbolic play in early childhood, or dramatic role-playing in middle childhood, they are not simply entertaining themselves. The boundaries of new cognitions and social relationships are tested, mental and physical muscles are trained and flexed, and adult roles are imitated in low-risk environments. Such behaviors are vital for learning and testing species-wide abilities (e.g., maneuvering the social hierarchy) while also discovering culturally specific technologies and roles (e.g., how to use a computer). For instance, many children in traditional societies spend much of their

time engaging in pretend versions of typical adult behavior, such as hunting or cooking [20]. Taking an evolutionary perspective on these behaviors allows us to make note of their functional elements as potential adaptations. Deferred adaptations are those behaviors in childhood that serve to prepare children for adulthood, whereas ontogenetic adaptations serve a beneficial purpose in childhood itself (for a more general discussion on the application of an evolutionary perspective to childhood [21].

Much of what our evolutionary forechildren learned would have been in the context of play. As we noted, formal education is evolutionarily novel in that it is a recent cultural invention that departs radically from the historically typical experiences of humans. Konner [2] has proposed that the modern hunter-gatherer childhood can be viewed as the cultural baseline, or model, for comparisons across evolutionary history. Some characteristics of hunter-gatherer childhoods are that children have substantial freedom to engage in activities within the community with little adult supervision, children of different ages interact together, and there is little direct teaching by adults [2, 3]. Extending this to education, Wilson and his colleagues [14] proposed that departures from ancestral environments can create unintended consequences and that efforts should be made to emulate traditional learning environments whenever possible. This includes learning in mixed-aged settings and making learning spontaneous, playful, and child-driven [11, 22].

This concept is not necessarily new, although it previously existed in a slightly different form. Vygotsky [23] proposed in his sociocultural theory of development that children acquire knowledge and develop skills necessary for survival and success within their social world by interacting with others, preferably others who are more knowledgeable and competent than they are. Central to this theory is the zone of proximal development, which refers to the difference between what a child can achieve on his or her own compared to what he or she can accomplish when scaffolded by someone who is more skilled in that domain. Children often perform new tasks in collaboration with others. But independent functioning is achieved when the scaffolding (or assistance) is slowly removed until children are able to perform the action on their own. According to this theory, most of the skills acquired in development occur most rapidly, effectively, and efficiently when children collaborate with others within their zone of proximal development, taking advantage of the assistance of more competent individuals.

Blank and White [24] suggest that although scaffolding would be ideal in an educational setting, it seems unlikely to occur in modern schools. For example, given the standardization of learning criteria, teachers must adhere to the curriculum schedule to ensure that all students receive the required information. Furthermore, for scaffolding to occur, a single teacher (the competent other in modern educational settings) must be able to extensively interact with no more than a few students at a time. Given the class sizes in most contemporary educational settings, this is not possible. The further segregation of mixed-age peers seems to eliminate another opportunity for scaffolding. Although such traditional pedagogy may seem unrealistic in today's competitive and high-stress educational systems, some schools have adopted such procedures with considerable success.

7.2.1.1 The Sudbury Valley School

An educational program that adopts a traditional approach to pedagogy is the Sudbury Valley School, located in Framingham, Massachusetts, for children between 4 years of age and high school age. The premise behind the school's educational philosophy is guided by the idea that each child is solely responsible for his or her own education. According to this perspective, if children are given a supportive opportunity-filled environment, they will, through self-directed play and exploration with peers across various ages, educate themselves or will be motivated to request the information from the staff at the school (see Gray [11] for a description of Sudbury Valley School and its philosophy). Peter Gray has described the Sudbury Valley School in detail and posits that the school's organization more successfully addresses the evolutionary novelty of modern education. Children in the Sudbury Valley School interact in mixed-age groups, engage in activities of their choosing, acquire most new information through play or games, and receive little or no unrequested direct adult instruction. These practices take into account the social and cognitive characteristics under which human children have learned for thousands of years, making the process of education consistent with the evolved neurocognitive architecture that allows such incredible amounts of learning in childhood. A central tenant of evolutionary developmental psychology is that the brain has not evolved in isolation from environmental input; rather, appropriate input is as vital as appropriate biology. Given the close relationship between the principles that govern Sudbury Valley's environment and the environment of human evolution, it is possible that an educational advantage could exist from this evolutionary model. Some readers may find this description ostensibly similar to Montessori education practices; however, Sudbury Valley School differs in many critical domains including true age mixing, pure democratic decision making, and child-driven curricula.

Formal classes at Sudbury Valley School are offered only in response to students' requests, but even then, there are no requirements for attending class. Books, materials, and knowledgeable staff members are available to aid in the learning of any subjects and skills, but students are always free to use or not use these resources. Additionally, there are no examinations or formal assessments. Most importantly, children are not assigned to grades or classes. They are encouraged to move through the school buildings as they wish. Children are often found playing, talking, and engaging in a range of self-directed activities. In this way, younger children interact with older children on a regular basis.

Allowing children to interact with peers of different ages seems to be essential for successful social learning. Evidence for this is seen through research with hunter-gatherer and other traditional, preindustrial societies that allow older children to guide younger children in their exploration of culturally relevant activities [25]. In fact, these studies find that self-directed age mixing has apparently been the primary vehicle of education throughout human history [11]. Although it is minimal, some research in non-traditional societies also suggests qualitative differences between children's interactions with adults and with their peers. This research is mainly

viewed through the lens of play. Given the minimal contact of mixed ages in modern schools, it is difficult to examine these interactions within educational settings. Elias and Berk [26] found the amount of time 3-year-olds spend talking with peers, while pretending is positively associated with the size of their vocabularies at age 5. Furthermore, spontaneous sociodramatic play with peers improved children's abilities to remember, reproduce, and comprehend stories [27, 28]. These findings suggest that using peers as scaffolds assists in the development and efficacy of learning.

According to Greenberg and Sadoffsky [29], this combination of free age mixing and the democratic ethos of the Sudbury Valley School is the key to success of its educational approach. Allowing children to choose what and when they want to learn fosters intrinsic motivation, creating a positive, self-motivated learning environment. Furthermore, the benefits of children of various ages interacting with one another are reciprocal. For younger children, it allows them to be able to watch older children's behaviors, learning from them through observation. Helping with the acquisition of new skills by younger children allows older children the opportunity to practice difficult skills that they themselves are perhaps still struggling to master. Additionally, it promotes empathy, critical thinking, and pride [11].

7.2.1.2 Too Good to Be True?

Given the description of Sudbury Valley School, one is inclined to question how well these children fare when they graduate and enter the "real" world. Follow-up studies of children who attended Sudbury Valley School suggest that students who graduate from this school perform just as well as students from other educational institutions [20, 29]. In these surveys, roughly 75 % of the graduates went on to pursue a higher education degree. Some even attended Ivy League institutions, with great success. Regardless of whether they attended college, on average, graduates of Sudbury Valley School were highly successful in attaining employment in their chosen careers [22, 30].

Greenberg and colleagues [30] and Gray [22] consolidated benefits of this program into four distinct categories. The first category was self-direction and responsibility. Given the minimal structure at Sudbury Valley and the personal responsibility instilled in the students there, graduates were able to take responsibility for their higher education and direct themselves into filling the gaps necessary for their success in higher education or the workplace. A second category is their high motivation for their field or path of education. The graduates expressed great interest and intrinsic motivation in continuing their education or entering the workplace in the field they chose to pursue. The third benefit concerned their skill in the given area of work or education chosen by graduates. These students chose to study or work in the area that they showed interest in while in school. Through their self-directed play and exploration, they acquired great skill in their area of interest and almost always went on to study or work in the field that corresponded to that interest. Lastly, graduates seemed to lack a fear of authority reported by many traditional students. Sudbury Valley graduates reported having positive

relationships with their professors or employers, communicated with them well, and were able to take directions without being defensive. Allowing children to direct their own learning, enlisting older children to help and teach along with able-bodied and sympathetic staff, and the incorporation of play and self-exploration are surprisingly effective education features. Even in the modern world with more standardization in the traditional classroom and longer school days and homework, children from Sudbury Valley School are able to compete and succeed in the social and professional world.

Evidence from education intervention programs also confirms the value of evolutionary principles. Wilson, Kauffman, and Purdy [31] created the Regents Academy program for academically at-risk 9th and 10th graders within their Binghamton, New York school system. The program's choice of guiding evolutionary principles focused largely on how to make cooperative small-group interactions as productive and efficient as possible, stemming specifically from the work of Ostrom [32, 33]. Using cumulative year-end grade point average as a comparison, the Regents Academy group significantly outperformed their matched sample who remained enrolled in the regular school. In fact, they were indistinguishable from the not-at-risk sample also enrolled in the regular school [31].

7.2.2 The Adaptationist Perspective

Adopting a large-scale naturalistic educational program, however, might be unrealistic in modern times. Therefore, others have argued that preschool education is particularly important and should reflect children's learning propensities, specifically, that beginning rigorous educational practices too early can be detrimental [34, 35]. This is consistent with the cognitive immaturity hypothesis [36, 37] which argues that infants' and young children's cognitive and perceptual abilities are well suited for their particular time in life and are not simply incomplete versions of the adult form. Along these lines is research with infants [38] showing that beginning a task too early in development can actually hinder subsequent learning. For example, Papousek [38] presented infants with an operant conditioning task (turn head in one direction to a bell, the other to a buzzer) beginning either at birth, 31 days or 44 days. He reported that infants who began training at birth required more trials (814) and more days of training (128) to reach criterion than the infants who started training at 31 or 44 days (278 and 224 trials, and 71 and 72 days for the 31- and 44-days-old infants, respectively). Papousek concluded that

> beginning too early with difficult learning tasks, at a time when the organism is not able to master them, results in prolongation of the learning process.

Although few people engage newborn infants in formal education, there are commercially available DVDs and educational software aimed at enriching infants' cognitive experiences. However, despite the testimonials on their Web sites, there is no evidence that these products enhance cognitive abilities, and recent research

indicates that they either provide no cognitive advantage [39] or may actually be detrimental to children's cognitive development [40]. Zimmerman and colleagues [41] reported that the amount of time 8- to 16-month-old infants spent watching "baby" DVDs such as Baby Einstein® was negatively associated with receptive vocabulary: Each hour children watched baby DVDs/videos was associated with 6–8 fewer vocabulary words. Moreover, although infants are often attentive to and seem to enjoy these DVDs as well as television, it is not until 18 months that the content of the video, rather than the physical stimulus qualities of the display, will hold a child's attention [42]. Although the research is admittedly scant, the evidence is consistent with the position that stimulation in excess of the species norm early in development can have detrimental consequences [43].

More research is available assessing preschool educational programs, contrasting the effect of formal instruction (termed direct instructional programs) versus programs that take children's "natural" propensities for play and activity into consideration (termed developmentally appropriate programs). There are few consistent differences in terms of academic performance at the end of a year between children who attend these two types of programs, with some researchers finding small advantages for the direct instructional programs, some for the developmentally appropriate programs, and others no differences [34]. When researchers look at long-term effects, however, different patterns emerge, with more studies reporting greater cognitive gains for children who attended the developmentally appropriate programs [44, 45]. In addition to the cognitive differences, children who attend the developmentally appropriate programs tend to experience socioemotional benefits; they experience less stress, like school better, are more creative, and have less test anxiety than children attending direct instructional programs [34]. Although the differences are small, most clearly favor the developmentally appropriate programs. In other words, any academic benefits gained from a teacher-directed program had its costs in terms of motivation. According to the authors of one study [46] that contrasted developmentally appropriate and direct instructional programs,

> If it has no clear benefit to the child's development, and if it may hinder development, there may be no defensible reason to encourage the introduction of formal academic instruction and adult-focused learning during the preschool years

Although these findings and interpretations may on the surface appear to contradict Geary's evolutionarily informed observation that direct instruction is necessary for children to acquire many of the biologically secondary abilities so important in modern societies, they do not. Instead, consistent with Geary, the findings show that young children should receive instruction compatible with their intuitive learning biases, which are well suited to the niche of early childhood. The ideas of Geary and those who advocate a form of education that minimizes the mismatch between modern learning and traditional learning also demonstrate that evolutionary thinking as applied to education is not monolithic, but rather that different Darwinian-influenced hypotheses can be generated and tested with the goal of improving education for the most educable of animals.

7.3 Implications for Policy and Practice

The obvious critique most academics or educators are likely to have of the addition of evolutionary reasoning to education is that the principles underlying their implementation can be derived just as easily without invoking evolution. Indeed, it is appealing to consider sharpening Occam's Razor and simply settle upon a system of "socially informed education." Shifting evolution into the background may be preferred and necessary in many occasions that may be encountered during the construction of a system for education. Day-to-day operations are, in fact, likely to be run along the lower-order level of adherence to rules that simply promote success among group relations. This is largely due to the evolutionary novelty of modern education. For example, in-group preference enabled small bands of hunter-gatherers to help protect the survival interests of their close kin and thus raise inclusive fitness. But in a modern educational setting, in-group preference may serve to foster trust and closeness for helping each other solve complex mathematics problems. However, these social principles function as they do because the human brain has evolved to place import on social stimuli, social situations, and social cognitions. We are nothing if not social animals. Given the increasing specificity with which cognitive and behavioral neurosciences are uncovering the brain's dedication to socialness [47], it seems advisable to retain evolution as a guiding theory for a social-based education. The provision of distal causation to proximate behaviors allows for integration and coordination of seemingly disparate aims related to development as a whole. As mentioned previously, evidence from evolutionary developmental psychology shows how the hasty introduction of certain stimuli or learning situations can lead to ultimately deleterious effects on cognitive development. Moreover, a new model was recently put forth reconceptualizing adolescent risky behavior (and intervention) based on evolutionary principles [48]. If education is to successfully integrate with these (and other) ideas, then an evolutionary perspective is insightful.

However, the goal of a traditional Western-style education system is to provide access to standardized education services to the entire populace, a difficult proposition given the size and diversity of most developed countries. In spite of the obvious difficulties, the current system works for a majority of children, as 78.2 % of American 9th graders in 2006 graduated from high school in 2010 [49]. Additionally, 65.9 % of 2013 American high school graduates enrolled in college, evidence that experience in the public school system translates, for most children, into higher education [50], although there are substantial ethnic, racial, and income differences. This system is certainly not perfect, but would it be worth the time, effort, and dollars to incorporate evolutionary-based education practices into the public school system? Is there evidence to suggest that the new system would be demonstrably more effective for the majority of children? Or is this style of education better suited for private schools or specific intervention programs?

Definitive answers to these questions will require years more research and assessment. Large-scale feasibility and longitudinal testing would be required

before any systemic changes can be reasonably proposed. However, we are confident that there is utility in an evolutionary perspective on education, even if it is not invoked in day-to-day decision making. The available evidence suggests that a system of evolutionary-informed education and intervention is just as successful (if not more so) as traditional education for professional outcomes while fostering greater positivity, enjoyment, and intrinsic motivation [11]. There seems to be little risk in incorporating these ideas into practice and few potential hurdles to implementation, with serious potential upside for academic performance and child emotional welfare. As society continues to search for the best manner in which to educate its members, it should, at the very least, give due process to incorporating evolutionary theory into the current functional system.

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