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An adaptive paradigm for human space settlement

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ABSTRACT

Because permanent space settlement will be multigenerational it will have to be viable on ecological timescales so far unfamiliar to those planning space exploration. Long-term viability will require evolutionary and adaptive planning. Adaptations in the natural world provide many lessons for such planning, but implementing these lessons will require a new, evolutionary paradigm for envisioning and carrying out Earth-independent space settlement. I describe some of these adaptive lessons and propose some cognitive shifts required to implement them in a genuinely evolutionary approach to human space settlement.

1. Introduction: an evolutionary context for space settlement

The genus *Homo*, originating in Africa on the order of 2+ million years ago, has dispersed widely across the globe (including settlement of the Pacific and Arctic over a thousand years ago; see [1] and Fig. 1) and even made brief forays beyond the protections of our planet, mostly to low Earth orbit, but also, briefly, to the Earth's moon. In non-human life, such broad distribution – into cold, warm, high altitude, arid, rain forest, and other environments – would be attended by biological speciation, physical adaptation to each specific ecological niche. But in humanity, for the past c. 100,000 years there has been no such biological speciation because humans adapt moreso by culture – complex behavior (including technology) – than by biology. This has allowed humanity to survive not because of our essential anatomy, but, rather, despite it. Humanity, then, has not flourished because of an internal drive to attain the 'pinnacle of evolution'–a common misconception – but because *Homo* rewrote the rules of evolution, inventing (we might say) invention itself, allowing us to adapt rapidly, specifically and proactively. Space exploration so far has been an *exploratory*, short-term concern, but there is also a modern resurgence of interest in one of the original motivations of space exploration, space *settlement* [2–6]. This would involve multiple generations (and would eventually be permanent beyond Earth), and thus, evolution, the process by which both biological and cultural information change through time [7,8]. Ensuring a good outcome of space settlement efforts, then, will require thinking in the long term (e.g. emphasis on large-scale patterns or the *longue durée;* see [9]) and a framework or guiding paradigm based on evolutionary principles. Specifically, we should structure long-term plans for space settlement on what we know of the evolutionary phenomenon of adaptation. Recent NASA documents, including the recent *Journey to Mars: Pioneering Steps in Space Exploration* explicitly mention 'evolutionary' and 'adaptive' design and design principles in the effort to explore space and then settle space habitats beyond Earth, permanently and entirely independent of Earth [10]; I agree that this is a worthy goal, and in this paper I provide guidelines for building such a genuinely evolutionary paradigm that

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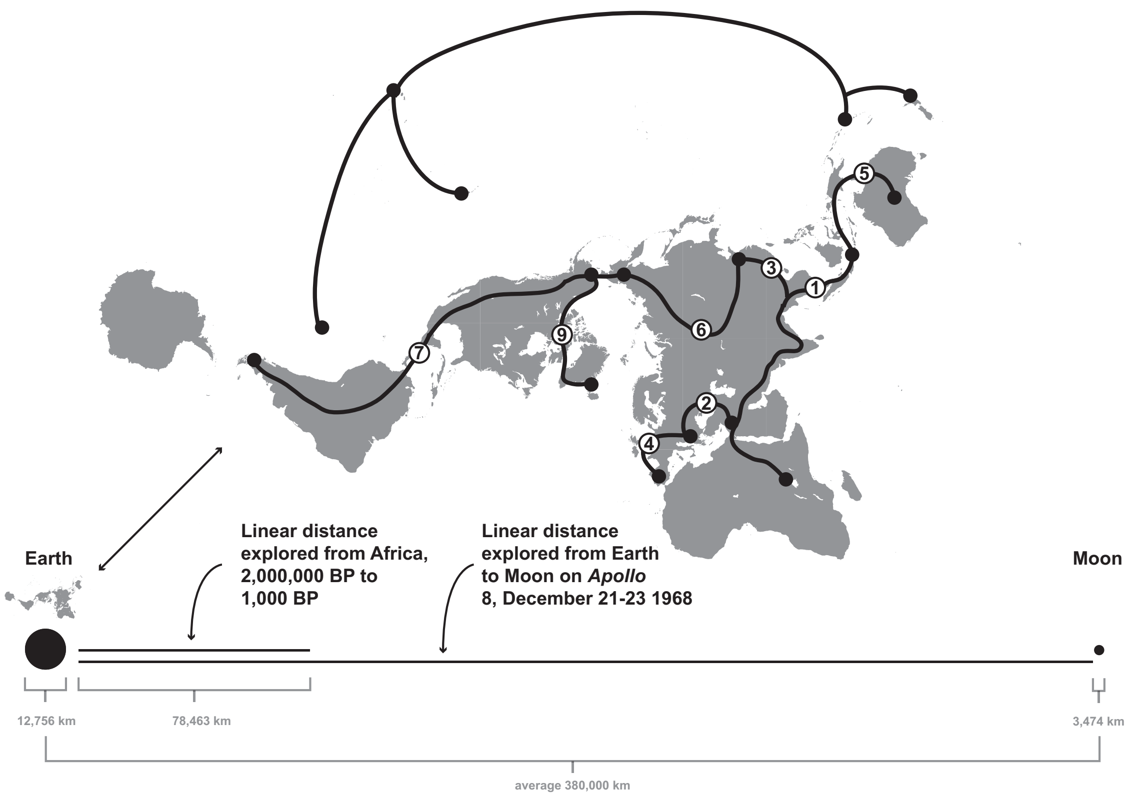

LEG	YEARS BEFORE PRESENT	LEG DISTANCE (KM)	CUMULATIVE DISTANCE from AFRICAN ORIGIN (KM)
1: Africa - SE Asia	2,000,000	14,247	14,247
2: Africa - W Asia	2,000,000	2,099	16,346
3: SE Asia - E Asia	1,500,000	2,555	18,901
4: W Asia - Europe	1,000,000	4,418	23,319
5: SE Asia - Australasia	50,000	6,018	29,337
6: E Asia - NE Asia	40,000	7,073	36,410
7: NE Asia - Americas	20,000	17,719	4,129
8: SE Asia - Oceania	3,000	18,482	72,611
9: NW Americas - NE Americas	1,500	5,852	78,463
10: Earth - Moon	50	384,400	462,863

Fig. 1. Human dispersal in prehistory: distances, prospective routes and comparison with distance to Moon.

could inform decision-making on levels from policy to engineering.

As a context for space settlement as adaptation, Table 1 outlines the four main large-scale adaptations so far in the genus *Homo*. The **Technological Adaptation** began on the order of two million years ago, when early *Homo* began using tools not just opportunistically – as we see in closely-related genera such as *Australopithecus* – but habitually, and eventually relying on such tools to survive. This adaptation allowed behavior to be decoupled from anatomy, beginning by using stone, bone, wood and antler artifacts to manipulate rather large, near objects (such as animal carcasses) and eventually results in manipulation of such small objects as individual atoms, and such distant objects as the *Voyager* spacecraft. The **Cognitive Adaptation** dates to about 100,000 years ago, when artifacts indicating symbolism and modern grammatical complexity – the key to human language – first appear, also in Africa; this adaptation allowed rich symbolism, leading to the capacity for abstraction and metaphor, allowing subtler understanding of the natural world and strengthening the bonds between groups of foraging people arranged in extended mating networks across large landscapes [11]. The **Domestication Adaptation** occurred in early post-glacial times, worldwide about 10,000 years ago [12]. Based on the capture of plant and animal species from the wild and selectively breeding them for human purposes, this adaptation led, in most areas, to the development of urbanism, civilization and rapid population growth. In short, a series of evolutionary transitions (see [13]) has resulted in shifting from opportunistic to habitual stone tool use, from simple, closed-system communications to rich, subtle, metaphoric language, and from pursuing calories to producing them, allowing humanity to

Table 1
Changes associated with biological and cultural adaptations in the Hominins. '+' indicates characteristic was increasingly important, '−' that it was less important.

Adaptation	Biological change involved: structural/ anatomical	Biological change involved: metabolic and process	Cultural change involved
Technological	+ Finger–thumb opposability	+ Hand/eye coordination	+ Enculturation time
Tool Use: by 2.5mya	+ Brain volume	+ Caloric needs	+ Econiche breadth
	+ body stature	+ caloric needs	+ Econiche breadth
	– Overall tooth size	– Digestion requirements (food pre-processed by stone and, later, fire)	+ Econiche breadth = reliance on technology = reliance on culture to teach complex tool use = decoupling of behavior from anatomy
Cognitive Modern behavior: after 100,000BP in *Homo sapiens*.	+ Brain volume	+ Caloric needs = More reliance on technology to process foods	+ Econiche breadth & or + econiche specificity & or active Niche Construction
	+ Brain volume and brain architecture complexity	= More complex social interactions	+ Cognitive variation/complexity = + behavioral variation
	– Overall tooth size		+ Cultural complexity and enculturation time
	– Body robusticity		
Domestication Harnessing plants and animals for human use: after 10,000BP in several areas worldwide.	– Body robusticity	+ Capacity for adults to digest certain farmed substances, such as lactose (in some areas)	+ Residential sedentism and task specialization in part resulting in establishment of protostates and civilizations
Extraterrestrial Will begin with earliest viable colonies biologically and culturally independent of Earth.	Unknown at present; under investigation.	Unknown at present; under investigation.	Unknown at present; under investigation.

adapt bioculturally to a wide variety of Earth environments in no single manner but with a mosaic of technological, cognitive and subsistence tools.

If the settlement of space succeeds it will constitute an evolutionary transition and adaptation on the order of those mentioned above, for which reason I refer to permanent space settlement as the *Extraterrestrial Adaptation*, which will be characterized by the establishment of human populations culturally and biologically independent of Earth those on Earth (termed '*Earth Independent*' by NASA in [10]). As mentioned, since this adaptation will be multigenerational, taking place over the *longue duree* involving slow migration of the centers of cyclic patterns (metaphorically speaking), so it will have to be planned with evolution in mind, requiring fundamental shifts in how we conceptualize humans-in-space, as introduced in Table 2. Before examining how space settlement can be designed as adaptation we will review of the principles of adaptive evolution.

Table 2
Non-evolutionary (exploration) and evolutionary (settlement) paradigms for human activities off of Earth.

	Space exploration	Space settlement
TIME	< 1 Generation	Multigenerational
SPACE	LEO & lunar = near	near & beyond solar system = far
UNITS	Administrative, e.g.hours, days	Lifetime = generations
CHANGE	Little to none	Continuous
MATERIAL	Expendable	Must be recycled
PHILOSOPHY	Completion of finite goals = ends	Establishment of new branches of human civilization = beginnings

2. Adaptive lessons for space settlement

As early as 1919 adaptation was concisely described as the "continuous adjustment of internal relations to external relations," [14] highlighting the maintenance of equilibrium between living things and their environments. Today adaptation may be used as a noun, in respect to a particular characteristic that makes life possible in a given environment, or as a verb when describing the process by which such characteristic accumulate in an organism's genome or behavioral repertoire over time; while previously such evolutionary mechanisms were thought only to be manifest in biological systems, recently social scientists have recognized that cultural information also changes by evolutionary processes – *Culture Evolves* is the title of the April 2011 issue of the *Proceedings of the Royal Society (B)* special volume on that topic – and in this paper I refer to both biological and cultural evolution and adaptation. Prosser provides a definition of adaptation well-suited to the project of human space settlement:

> "The capacity to live in an environment not occupied by forebears indicates that adaptive evolution has

occurred. The essence of evolution is the production and replication of adaptive diversity." [15]

For nonhuman life forms, such adaptation and evolution are reactive and undirected by any centralized, decision-making process (of course, pattern, complexity can and do result from unintentional processes [16]). In humanity, however, there is an awareness of time and space and a conscious use of technology that allows proactive self-direction of evolution, particularly in the rapid tailoring of behavior (including social organization and moral codes, for example) and technology to changing environmental circumstances. An understanding of evolution, then, will be a potent tool for human space settlement.

Evolutionary approaches to a variety of human goals other than space settlement have been successfully attempted in the fields of *biomimicry* (engineering based on naturally-evolved designs and processes; see [17]) and *'darwinian programming'* that evolves designs by evolutionary processes [18]. In the same way that these attempts were based on evolutionary principles and an adaptive paradigm conditioned their approaches, in the remainder of this paper I discuss some of the lessons of adaptation – as studied by paleontologists, biologists, anthropologists and other evolutionists – as they could assist in the building of an adaptive framework for human space settlement. We may begin with three basic lessons of adaptation derived from a literature review of decades of adaptation research see [19]; while I am specifically applying these lessons to the project of human space settlement in other, forthcoming work, they are provided below to stimulate thought among other space planners:

2.1. Lesson 1: adaptations arise from ecological opportunities

Lossos and Mahler point out that a prerequisite for adaptation is the availability of an ecological niche, or habitat, for settlement [20]. For human space settlement, the lesson is deceptively simple; begin by identifying habitats available for human settlement. This becomes a large project, however, when think in terms of generations rather than just years, and we consider how such habitats or niches might themselves change over time, requiring humanity to adjust; or that human intentions and wishes might themselves change over time, such that a given niche will no longer be sufficient to sustain human populations or interests. An evolutionarily-informed, adaptive approach to identifying suitable niches for human settlement should include consideration of the time dimension. For example, Mars or other solar system settlements should be designed considering the change through time of the nature of the settlement; e.g. from early outpost (small population of agriculturalists and fabricators with facilities and resources so scaled) to local hub (larger population of specialists supplied by exterior agriculturalists, and increase of administrative functions and facilities), and settlements must be designed to accommodate the needs of not just individuals, but families and other identity groups (e.g. extended families) that themselves change through time. This requires consideration of time units; years of human life are familiar, but other units, such as generations (concerning demographics and population genetics) or units related to agricultural potential and productivity – and many others – should be considered in space settlement planning (note that such 'ecological time scales' will have to be considered not only for humanity and its many species of microbial symbionts, but also for all of the domesticates taken off of Earth).

2.2. Lesson 2: learn from adaptations in nature

Vermeij has studied the characteristics of adaptive systems at large, and specific adaptive properties of individual organisms, to identify patterns in how life forms go about "...averting, neutralizing, blunting or eliminating unpredictable threats." [21] These include

(1) Threat adaptation by tolerance via passive resistance.
(2) Active engagement to disable and/or eliminate a threat with force.
(3) Increase knowledge of threat to make it more predictable.
(4) Increase unpredictable behavior to prevent threat from predicting your actions.
(5) Isolate and starve threat of resources.
(6) Use redundancy/modularity to make local losses sustainable.
(7) Decentralize control to make local losses sustainable.

An example of a lesson here is the reminder that starving a threat can be effective, and the capacity to quarantine – while remaining a viable, functional, settlement – should be built into the architecture of space settlements, particularly early on when populations are relatively low and tightly-packed, and the risks of infectious disease are concomitantly high see, for example, [22].

2.3. Lesson 3: benefits of collaboration

Three decades of the 'genomic revolution' have demonstrated that no life form is solitary; even the microbes, which we might think of as solitary, anonymous 'germs', have active lives involving signaling and reciept of signals from other microbes [23]. Biomimicry pioneer Jill Benyhus has outlined some of the adaptive lessons of collaboration – intentional and unintentional – in living communities [17], summarized below.

First, collaborative efforts allow the pooling of resources, as when many sensors are used in the same search for resources, rather than a single sensor. Second, collaborative efforts can 'extend' the body in space and time, as in the case of ants that form bridges for other ants to crawl across. Third, collaborative allows rotation of effort among community members, such that some rest while others work. Fourth, collaborations allow the 'swapping' of skills, such that reciprocal arrangements maximize the potential of differences rather than uniformity in a system. Fifth, individual risk is also minimized by collaboration; for example, habitats may be divided among community members in a way that each is fitted to their own special niche, maintaining diversity rather than trying to 'enforce' uniformity, which has multiple downsides.

2.4. Lesson 4: biological adaptations are sustainable

Life forms that overrun their resources experience population collapse or extinction (a point being largely resolutely ignored by modern civilization). This will not work, of course, in off-Earth settlements, where resources will, at least for many early generations, be relatively scarce (relative to on Earth). Space settlement will have to be preeminently sustainable.

A shortlist, then, of guiding adaptive principles to inform human space settlement plans should include the following:

- sustainability over ecological (multigenerational) time;
- modularity to sustain system perturbations; and
- collaboration for multiple benefits.

Of course, while these aspects of biological adaptation might well improve our adaptations to space environments, we do not need to be enslaved by them; they may be thought of as guidelines, not shackles. But inasmuch as various design endeavors have been profitably guided by evolutionary principles, awareness of these elements of billions of years of adaptations in Earth's living systems should better align human adaptations to the dynamic – rather than static – nature of the universe.

Finally, three lessons from palaeobiology (see [24]) should be built into the strategic decision-making processes that shape human space-settlement plans. The first lesson is that the longest-lived species exist in *large populations* allowing for survivors of even widespread species disasters. Humanity currently has a population of about six billion, a number that has doubled in just the last c.40 years. In terms of sheer numbers, our species can be considered successful, but we should recall that it is in the invisible world of the microbe that the most numerous life forms are found. When considering human space settlement, then, we should move away from ideas of small, fragile, outpost populations and towards the idea of (and plans for) humans moving to space not to live marginally, but in profusion; my own work suggests founding populations on the order of tens of thousands, rather than hundreds as proposed some decades ago by other authors [25]. Space settlements design should promote large and growing populations from the start.

The second lesson is that long-surviving populations are w*idespread* in both general space (e.g. across the entire planet) and specific ecological niches (e.g. tigers being capable of surviving both hot, tropical environments and cold, temperate environments). Such distribution also allows for survival of some species or individauls of single species when others are selected against either in the short- or long-term. Space settlements should be designed to occur not just in earth-orbiting communities, or moon colonies, or on the surface of Mars and other nearby planets and bodies such as asteroids, but in *all* of these locations and more, extending out, eventually, to other solar systems via interstellar exploration and population dispersal. Further, space settlement should be designed not as a concretely-delineated project with a discrete end goal – as was the *Apollo* moon landing program that was terminated after the 'goal' was attained – but as an open-ended, infinite process with the nebulous goal of spreading humanity far and wide, eventually to even the interstellar realm.

The third specific lesson of evolutionary survival is that long-lived species have been *behaviorally and/or genetically diverse*. Genetic diversity is a hedge against change in selective pressures (environmental factors that 'evaluate' the fitness of a population members), which can be expected because nature is dynamic rather than fixed. In short, variations which were yesterday neutral or of little value (or might even have been deleterious) can become necessary for survival under a new selective regime. The same applies to behavior, especially for a species (such as humanity) that relies more on its behavior than its genetic constitution to survive. While our biological structure must allow basic survival, humans shield that bodily frame from many selective pressures with myriad behavioral adaptations, including the construction of tools, shelters, clothing and methods of water purification, cooking, and so on, extending even to the significant complexities of human social interaction. Just as geneticists measure the health of a given species in terms of its genetic variability, then, human cultural health should be considered in terms of our cultural diversity, which allows the behavioral flexibility required for long-term survival. Of course, precisely this diversity has been used by tyrants, for as long as we know, as the basis of conflict, and as with any invention or process, it must be admitted that it can be the source of either solutions or problems. The chief lesson here is that space settlement should be planned to incorporate both genetic and cultural variation. There is a place for uniformity in both domains, but there is no 'ultimate' cultural solution or any genetic 'master race' exactly because selective pressures change. If there is a 'master solution' that has been shown to persist, it is that of manipulating rather open-ended proactive adaptation in the genus *Homo*. Implementing this nebulous goal may partially be accomplished by explicitly invoking these adaptive principles in discussion and consideration of human space settlement, a task now underway in my own work [26].

3. Building an adaptive framework for human space settlement

An ‘adaptive framework for human space settlement’ may be thought of as a cognitive skeleton, the structure of which conditions the thoughts that lead to actions – the fleshing out of a whole body. An example from the emerging field of biomimicry is illustrative. First outlined by Janine Benyhus (mentioned above), this list of general observations structures the progress of her field:

(1) nature runs on sunlight,
(2) natures uses only the energy it need,
(3) nature fits form to function,

(4) nature recycles everything,
(5) nature rewards cooperation,
(6) nature banks on diversity,
(7) nature demands local expertize,
(8) nature cubs excesses from within, and
(9) nature taps the power of limits.

Benyhus' principles were, in turn, adapted by architects Daniel Vallero and Chris Frasier in their principles of sustainable, evolutionarily-informed design [27]:

- waste nothing (less is more),
- adapt to the place (learn from indigenous strategies),
- use free resources (renweable & abundant resources),
- optimize rather than maximize (use synergies, reduce mechanization), and
- create a livable environment (build for life, not against life).

If human space settlement is to succeed it will have to be designed as a long-term, adaptive endeavor, proactively guided to realize the Extraterrestrial Adaptation. To do this, it cannot be carried out with the short-term, goal-seeking behavior that has characterized some of the human space program so far. That approach has highlighted technology, *which allows human life in space*; whereas to fully embrace the evolutionary perspective we should highlight *living in space*, with technology subordinate to the goals of extending life far beyond Earth. Another way to highlight the evolutionary nature of human space settlement is to cast humanity *adapting to* space environments, rather than *conquering* them; adaptation is a long-term, natural, evolutionary process, whereas conquest is a shorter-term, episodic phenomenon. The shift is subtle, but as in poetry, subtle shifts can be very powerful; we will review these issues below, particularly in Section 4.2.

4. Paradigm shifts for adaptive space settlement

The short-term approach to thinking about humans in space must be overhauled to realize the Extraterrestrial Adaptation. For the moment, we can ask, how does one overcome embedded structures of thought? Essentially, a *paradigm shift* must be made. The paradigm, as formulated by Thomas Kuhn, is a set of accepted practices, a consensus on what is to be observed and analyzed; it conditions the questions that are asked and how the results of experiments are analyzed. When it allows errors the paradigm becomes harmful to the generation of new knowledge, and a paradigm shift is required [28]. Resistance to paradigm shift is often found in the e phenomenon of *groupthink*, in which a collective set of systematic errors is perpetuated by a group because of general resistance to change and the collective momentum of the status-quo [29]. This can be difficult to overcome but it is exactly this kind of status-quo about humans-in space, engrained in the popular culture, that must be overcome.

Paradigm shifts often occur in subtle but powerful ways including how people communicate in casual talk; the sets of words and ideas used for basic information exchange shapes the conversation. Somewhat more formally, they can also be encoded in textbooks; a recent undergraduate text, *Sustainable Design: The Science of Sustainability and Green Engineering*, provides an excellent example of the thin end of a paradigm shift wedge:

> "It is only through creating a better understanding of the natural world that new strategies can emerge to replace the entrenched design mind-sets that have relied on traditional schemes steeped in an exploitation of nature. Designs of much of the past four centuries have assumed an almost inexhaustible supply of resources. We have ignored basic thermodynamics." [27]

The sustainability paradigm is also seen in the US National Academy of Engineering's *The Engineer of 2020: Visions of Engineering in the New Century*:

> "It is our aspiration that engineers will continue to be leaders in the movement toward the use of wise, informed, and economically sustainable development. This should begin in our educational institutions and be founded in the basic tenets of the engineering profession and its actions." [30]

Building a new cognitive framework, then, that will condition basic thought about the larger thought-domain of humans-in-space in the long term, will best be done by a series of cognitive shifts implemented by its inclusion in undergraduate (and earlier) education. While we cannot talk our way into space, we do need a vocabulary that moves us away from archaic ideas towards more modern ideas. Generating these new terms and ideas will requiring a number of *cognitive shifts*, discussed below; I am happy to say that many are well underway, particularly as the 'Second Space Age' (focusing on lowering the cost of space access, and on Mars as home to a new branch of our species) develops.

4.1. Cold war/miltaristic → humanistic/families in space/people

This shift involves demilitarizing the motives and carrying out of space access and settlement. While military agencies have served an important role in developing space technology so far, space settlement will be in large part about civilian organizations, families and communities building a civilian rather than military culture off-Earth. Additionally, the cold-war overtones of control and competition related to the 'Space Race Era' must be replaced with language that emphasizes everyday civilian life.

This shift will occur somewhat naturally as private industry is increasingly engaged in providing direct access to space, and as legal mechanisms establish codes of conduct in off-Earth environments. The essential message here is the humanization of space for peaceful purposes.

4.2. Industrial/mechanical → human/organic

This shift involves moving away from conceiving of science, technology, mechanism and industry as ends in themselves – or necessarily linked, as in the name of Oregon's 'Oregon Museum of Science and Industry' – and towards conceiving of these as human inventions meant to aid in adaptation. Science, for example, is a method, and can be used for industry or the pure generation of knowledge, or even for enjoyment, and need not always be associated with its material precipitates and their commodification. On *Discovery* magazine's main website, for example (and in many newspapers), as on Fox News' main website, news from science and technology are unnecessarily (and, strictly speaking, improperly) combined in sections titled 'Science/Technology'.

This large-scale cultural shift of values would recognize that the science which makes humanity particularly adaptively competent is not necessarily bound to technology and commerce. Further, it would emphasize that technology is not necessarily an end, but a tool for adaptation. Working with high technology–human interface in highly demanding environments, Special Operations Command General Schoonmaker recently pointed out that "What is important is to equip men, not man equipment."[31].

4.3. 'The right stuff'/NASA complex/professional → everyman/pioneer

This shift involves moving away from the conception of humans-in-space as the sole domain of a small, privileged few highly-trained space professionals, and towards the inclusion of 'everyman', the general public, because it will be large populations of civilian non-space professionals that will form the bulk of off-Earth colonists. While some high-level professionals, such as spacecraft pilots, will always of course be necessary, space and access to space must be disengaged from the concept of exclusivity.

Implementing this shift will, like some others, occur naturally as NASA is increasingly devoted to long-range space exploration and research, and private access to space becomes cheaper and more commonplace. Structures should also be established to reward the reinvention of essential space-exploration technologies, such as EVA equipment, to be cheaper and more field-maintainable than those produced by the titanic federal systems so far employed. As in many cases, a substantial part of this shift should take place simply in conversation, socialization and education. We would do well to point out that any given space settler will more likely be a farmer, plumber or teacher than a test pilot.

4.4. Short-term, limited goals → long-term, infinite future

This shift involves moving away from the conception of humans-in-space as a short-term 'project' with an endpoint, towards a conception of a long-term future. In other words, space settlement should be recast as a beginning for the rest of human history, than any kind of pinnacle or end. There is no knowing what will come of humans settling off-Earth environments, but humanity remaining on Earth would most likely result in extinction in the long term. For this reason, the author H.G.Wells noted – even at the turn of the 19th–20th century – that for humanity "It is all the universe, or nothing."

This cognitive shift requires an emphasis on time and evolution and their internalization by humans; they must be believed as being important. Deep time – the recognition that the Earth is billions, rather than some tens of thousand of years old – must be internalized, as must evolution. There is no end to evolution except in extinction, and the ultimate goal of human space settlement is the prevention of extinction of *Homo*, at least for some millions of years, at which point we may well have evolved into another variety of life that is not, hopefully, Earthbound, but distributed widely in the solar system and perhaps farther.

4.5. Exploration → settlement

While humanity will always be exploring, the role of space settlement must be separated from the current exploration-mode conceptions of humans-in-space. Most space colonists will be family people, building new civilizations, rather than the professional explorers noted above. In time, they will not leave Earth laden with the idea that they must return to Earth.

Achieving this shift will occur naturally as off-Earth colonies are established and flourish, achieving a sort of cultural normality; 'Of *course* there is a Mars colony' we hope people will argue in the near future, rather than 'Why would we build a Mars colony?'. But even in the run-up towards the time of the first off-Earth settlements, the shift will have to take place such that space is not just a place where exploration takes place, and where only explorers go; it must be recast as a place where common people can go to have families and descendants.

4.6. Conquest of nature → adaptation to nature

This shift involves a significant reconsideration of the relationship of humanity to the rest of the universe; away from the concept that humanity does or can 'conquer' Nature (including space) and towards the concept that humanity adapts to Nature, and will adapt to space environments. Werner von Braun's influential 1950s *Conquest of Space* series, published in a thrillingly-illustrated series of Collier's magazine issues, was important to building support for manned space exploration in the 20th century. However, the conception of humanity conquering Nature is at odds with everything we know about evolution. There is, in fact, no Nature to conquer; only environments to which humanity can adapt; and if those environments change, humanity will have to change with them. There is no such thing as conquest, in the long term. In evolutionary time, one must remain flexible and continue to adapt. 'Conquest' is specific, and therefore limiting. Adaptability is general and limitless.

This shift, as others noted above, also requires learning and internalizing the fact that humanity is one of millions of species, and has only relatively recently arisen (and this by the evolutionary process of adaptation), and could easily become extinct. Our 'conquest' of any given environment has not yet stood a long test of evolutionary time. Therefore, science education, and general speech and socialization should put a premium on the concept of the processes of adaptation rather than 'final conquest'.

4.7. *Limitations to humanity → increasing human options*

This shift involves a move away from concepts of human space settlement as being a province of hardship, stress, and limits to freedom, and towards a conception of its *removing* limitations and providing humanity with many more options – in an infinite universe – than are available when constrained to living on Earth. A popular conception of the perceived limits to life off-Earth is found in an essay by William Hodges:

> "...for generations [of early space colonists] the settlers will be poor. They will spend their entire lives in conditions of extreme material deprivation and high risk of death." [32]

While the material life of early space colonists will certainly be different from those of, say, modern suburban Westerners, 'deprivation' seems a strong term. In a countering essay (in the same volume), Edward Regis, Jr. points out that because at least the earlier off-Earth human settlements will have to be well-managed and will be unable to support the kind of explosive population growth we have seen on Earth,

> "Far from being severe deprivation...all the generations to be born...are to be well provided for throughout their life spans, something that could not be said for most of the children who have been born on Earth." [33]

Achieving this shift requires engaging the mind with a creative, expansive, and ultimately optimistic philosophy when discussing the human future in space. Certainly, space colonies will for a long time require different modes of life than many of us live on Earth. But it is important to remember that many humans today – the bulk, actually – live in conditions of poverty and overcrowding. Such conditions will not be possible at least in the earlier generations of off-Earth migration (even if they are relatively large), as resources will be too limited to allow them. Artwork depicting prospective off-Earth settlements must emphasize such optimism, freedoms and expanses, rather than constraints.

4.8. *Barely possible → possible and routine*

This shift requires a move away from the conception of humans-in-space as an exception, something that is rarely done because of its expense and technical challenges, towards a conception of humans routinely going into – and remaining in – off-Earth (space) places.

Like some other shifts, this will occur rather naturally as the cost of space access is reduced (with inflatable habitats and 3d printing likely to figure large in such cost reduction) more people enter space and spend more time there. Ultimately, children will be born off-Earth, and never visit Earth; they will be the first Extraterrestrial human generation. Such a provocative concept must be communicated and explored with optimism and a de-emphasis of the machinery in exchange for an emphasis on the humans who will build and use that machinery. We should remember to converse about how lives will be lived out, what kinds of careers people will have off of Earth, and not just what technologies will be required for survival.

4.9. *Destiny/march of progress → human-directed evolution*

This shift requires a move away from the conception of humanity being destined to march triumphantly into space, and towards the conception that humanity will only succeed in space settlement through proaction. As the great evolutionist G.G. Simpson wrote in the mid-20th century:

> “There is no automatism that will carry [humanity] upward without choice or effort and there is no trend solely in the right direction. Evolution has no purpose; man must supply this for himself.” [34]

This shift, like others mentioned above, will require an internalization of the fact that evolution is not internally driven 'to' create any given form of life; nor does evolution usher any given form of life through predetermined stages. Evolution is simply the change of life forms over time, a *consequence* of the facts of replication, variation and selection. When evolution is properly understood, then, as must be achieved through education and in the general public culture, it is clear that humanity cannot wait for or simply expect preordained success in colonizing space, but will have to build that success by proactive adaptation.

4.10. *Costly luxury → responsible investment*

This shift requires a move away from the idea that human-in-space activities are a costly luxury towards seeing such – including human space settlement – as a responsible investment in the human future. Economically, there is perhaps never a 'good' time to engage in space exploration (not to mention settlement); space exploration has been expensive to date (though human access to space will in the near future become radically cheaper), and startup costs for human space settlement will certainly be high in dollar terms.

This shift can be assisted by pointing out that while cost in dollars will be high at first, our species routinely invests in long-term projects at vast expense, such as the cathedrals of ancient Europe, or the modern Large Hadron Collider (also note that many spaceflight costs are artificially high, as is being discovered by private space access companies today). However the costs are calculated and modified, it is likely that, particularly when distributed among several nations and private efforts, and spread over some years, space settlement would be of high to moderate cost, but is not impossible. In fact, it should be pointed out that avoiding space settlement may be penny-wise, but pound-foolish, as a moderate expense now could prevent bankruptcy – extinction of our species or the beginning of a new Dark Age by any number of factors – later.

4.11. Spinoff justification→survival justification

This shift involves a move away from the question 'what will we on Earth gain from space settlement?' towards the realization that what we will gain is survival – or at least a better chance for the survival of our species and civilization than we would have if we remain on Earth. Understandably, NASA has for most of its existence published lists of *spinoff* inventions – microwave ovens, digital wristwatches and so on, resulting from space-exploration technologies – in part to justify its existence. But such material gains, while substantial, cannot be the justification for larger humans-in-space activities, including human space settlement. The mentality must, at least, include the survival of our civilization and species as a significant and worthwhile result of space settlement.

This shift will require a greater appreciation, in the public culture, of the threats to civilization, and our species, posed by ourselves (e.g. warfare), Earth-based biology (e.g. plague) and extraterrestrial threats, including Earth being struck by a comet or asteroid (See Fig. 2, indicating collapses in all ancient civilizations) [35,36]. Every few years the media run dramatic stories about solar flares that threaten communication satellites, and, thus, internet access and even cell phone operation. Improving an awareness of the possible threats from outside Earth could be accomplished by, among other methods, publishing 'space weather' bulletins in the mass media, in tandem with the usual Earth weather forecasts.

4.12. Technospeak→common speech

This shift, related to all of the above in one way or another, entails a move away from the specialized, technocratic language of acronyms and unfamiliar terms relating to humans-in-space and towards a 'normalization' of how we speak about, and think about, humans-in-space.

Certainly, acronyms and specialized language are necessary and appropriate for managing space programs, but they are alienating and counter-productive when attempting to engage the general public, beyond a certain point. The interface between engineers and the general public must be shaped so that it does not alienate, but rather opens the field of thought for discussion. Engineers and other scientists interfacing with the public should receive some training in popularizing their field (effective use of metaphor, for example), and basic education should include discussion of science as neutral, something that can be used responsibly (electric lights) or abused (nuclear and biological weaponry).

As mentioned above, this shift is subtle, but, as in poetry, its subtlety is derived from its essential simplicity. Using different words – some of which might need to be invented – to communicate to one another about humans-in-space at large can help to normalize the concept of human space settlement. In *Realspace: the Fate of Physical*

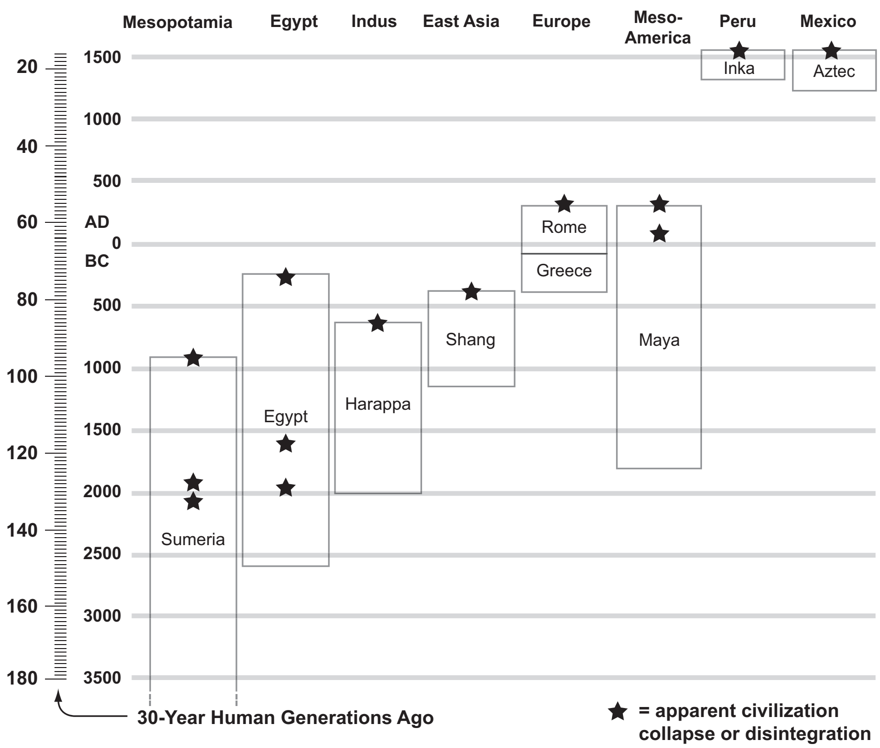

Fig. 2. Disintegrations of ancient civilizations.

Table 3
Some possible new terms for humans-in-space activities focusing on the long-term.

Old words/terms	New words/terms
Space exploration	Space travel
Astronaut	Space traveler, colonist, voyageur
Caspule, spaceship, rocket	Vessel, ship, pirogue, lighter, caravel, spore, pod, seed, tendril, galleon, bergantin
Base/habitat/colony	Village, home, city (use Earth terms)
Extraterrestrial	Off-Earth

Presence in the Digital Age, On and Off Planet, P. Levinson recently wrote:

> "So the need is not to find a new medium of communications, but a better way of communicating about space through media already in play. We can begin with the very way we talk about our space vehicles. Starships are more enticing than space shuttles; cloud offices are more inviting than space stations. A name such as 'Mermaid Dune' – given to a Martian rock site identified in NASA's 1997 Pathfinder mission – is a minor step in the right direction. It humanizes an alien environment, in contrast to 98-BLG-35 and the alphanumeric soup of appelations often given to new meteorites, asteroids and even possible planets discovered in other solar systems." [37]

Words, in short, are important. In Table 3 I present some rough ideas for the significant realm of *renaming*. While we cannot talk our way into space, the words we use in discussing space settlement are important; the words we use can frame the project as a short-term goal with technology at the center and humans at the periphery, or they can frame it as an open-ended development in which humanity is engaged in a new adaptation as momentous and promising as several before in our evolutionary history.

5. Summary and conclusion

The cognitive shifts noted above would largely place humans and evolution at the center of human space settlement, moving away from technocracy and towards a paradigm of space settlement based on the evolutionary and adaptive principles that have served for long-term success in many forms of Earth life. Implementing these shifts in core concepts requires attention to the way we communicate about space exploration and settlement, and inclusion of these concepts in space-education materials. Implementing these shifts on the policy level will take time as students educated in this atmosphere themselves become the policy-makers. I am happy to see that some are already underway, and I will continue to familiarize space planners with evolutionary principles as my own contribution to the larger goal of the Extraterrestrial Adaptation.

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