Journal of the Association for Information Systems
JAIS

Research Article

Four Guiding Principles for Research on Evolved Information Processing Traits and Technology-Mediated Task Performance

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Abstract

Evolved information processing traits are defined as mental traits that have been evolved by our species in response to evolutionary pressures and that are associated with the processing of information. Evolutionary psychologists and human evolution researchers have long realized that theorizing about evolved mental traits is very difficult to do in ways that lead to valid testable predictions. Quite often that theorizing leads to what are known as Panglossian (or naïve) explanations, which may at first glance be seen as valid evolutionary explanations of observable traits, but end up proving to be wrong and misleading. We propose four meta-theoretical principles to guide future research on evolved information processing traits and their effects on technology-mediated task performance, and help researchers avoid Panglossian explanations. We argue that this type of research holds the promise of bringing fresh insights into the study of human behavior toward information and communication technologies, and thus, helping advance the field of information systems through a promising path that has rarely been taken before. We derive the four principles from mathematical formulations developed based on two of the most fundamental conceptual tools employed in population genetics and mathematical modeling of evolutionary processes: Fisher's Fundamental Theorem of Natural Selection and the Price Equation. We provide an illustration of the application of the principles through an empirical study of a technology-mediated learning task. The analysis was conducted using WarpPLS 1.0. The study provides support for a puzzling phenomenon, known as flashbulb memorization, the context of web-mediated learning.

Keywords: *Information Processing Traits, Evolutionary Psychology, Fisher's Theorem, Price Equation, Technology-Simulated Threats, Flashbulb Memorization*

* Dennis Galletta was the accepting senior editor. This article was submitted on 26th January 2010 and went through two revisions.

Volume 12, Issue 10, pp. 684-713, October 2011

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1. Introduction

The study of evolved information processing traits and their effects on technology-mediated task performance arguably holds the promise of bringing fresh new insights into the study of human behavior in contexts shaped by various information and communication technologies (Dennis & Taylor, 2006; DeRosa, Hantula, Kock, & D'Arcy, 2004; Hantula, Brockman, & Smith, 2008; Hubona & Shirah, 2006; Kock, 2004, 2009; Porra, 1999; Porra, Hirschheim, & Parks, 2005; Rajala & Hantula, 2000; Saad, 2008; Smith & Hantula, 2003; Spink & Cole, 2006). Evolved information processing traits are defined here as mental traits, associated with the processing of information that reaches us through our five senses, and which have been evolved by our species in response to selective forces related to one or more fitness-impairing events (Kock, 2009). These are events that, by definition, reduced the reproductive success of individuals in our ancestral past; e.g., encounters with large predators. (For convenience, a list of key terms and definitions is provided in Appendix A).

Nevertheless, unfounded evolutionary theorizing can easily derail the potential of the study of evolved information processing traits and their effects on technology-mediated task performance. We use the term "technology" here primarily to refer to information and communication technologies, and it should not be confused with ancestral technologies, such as stone tools and fire.

Evolutionary theorizing seems to be particularly vulnerable to nonsensical speculation (Buss, 1999; Cartwright, 2000), perhaps because of the apparent simplicity of the process that leads to the evolution of traits (morphological, physiological, mental) that enhance the replication potential of the genes that code for those traits. Mathematical formalizations of various aspects of the evolution of traits (Haldane, 1990; McElreath & Boyd, 2007; Rice, 2004), either through selection (fitness enhancement) or genetic drift (by chance), have led to the realization that the processes underlying the evolution of traits are not as simple as the popular media often represent them to be (Wilson, 2007; Zimmer, 2001).

The main goal of this paper is to provide focused and parsimonious guidance to information systems researchers interested in the study of evolved information processing traits and their effects on technology-mediated task performance. The guidance comes in the form of a set of four theoretical principles and related guidelines. These principles are not theoretical propositions or hypotheses. Rather, they provide a basic roadmap for the development of propositions and hypotheses, and their testing in the context of information systems studies. As such, the four theoretical principles and related guidelines can be seen as a basic epistemological contribution to the information systems literature.

The goal of this paper is not to propose a full epistemology (Audi, 2003). Nevertheless, the four guiding principles and related guidelines can be seen as the beginning of a new epistemology, with applications that go well beyond the field of information systems. Information processing is a central issue in the field of information systems and also plays a key role in many other fields. Therefore, the principles and guidelines may contribute, even at this early stage, to further enhance the potential of information systems as a reference for other disciplines (Baskerville & Myers, 2002).

2. Evolution's Potential to Explain Behavior toward Technology

Some evidence of the promise that explanations and predictions based on evolved information processing traits may hold for technology-mediated task performance research is provided by the emergence of a new field of research in the 1990s, known as evolutionary psychology (Barkow, Cosmides, & Tooby, 1992; Buss, 1999). Evolutionary psychology is primarily characterized by basic, as opposed to applied, research. Evolutionary psychologists generally focus on theorizing and showing evidence that certain mental traits have been evolved through selection, as opposed to showing evidence that those evolved traits can be used for practical purposes. Nevertheless, the main underlying idea of this new field of research can be used for the understanding of behavior toward technology. That main idea is that the brain of modern humans has been largely designed to solve problems faced by our Stone Age ancestors (Buss, 1999), which should lead to observable human behavioral patterns today in contexts where modern technologies are used.

There are examples of information systems theorizing based on evolutionary psychology, but these are still rare. For example, Kock (2004, 2009) used evolutionary psychological ideas to develop a theory of media naturalness that arguably solves some of the conceptual and theoretical problems associated with media richness theory (Daft & Lengel, 1986). The latter is a theory that has often been used to predict behavior toward electronic communication technologies and task performance outcomes achieved by groups communicating through those technologies (Kock, 2004). Simon (2006) demonstrated empirically that media naturalness theory can provide a successful replacement for media richness theory. His investigation shows media richness theory to be problematic when used for theorizing about behavior toward technology, even though it has been one of the most widely cited theories in the field of information systems. One of the main problems is that media richness theory hypothesizes media effects at the task outcome level, which have often been shown not to hold in several different contexts (El-Shinnawy & Markus, 1998; Garza, 2011; Kock, 2001; Lee, 1994; Markus, 1994; Ngwenyama & Lee, 1997), whereas media naturalness theory hypothesizes media effects at the cognitive level that seem to occur with great frequency. Those cognitive effects may or may not lead to certain task outcomes (Garza, 2011; Kock, 2001; Simon, 2006).

Further examples of successful evolutionary thinking applied to the understanding of behavior toward technology are provided by Hantula et al. (2008), Saad (2008), and Porra & Parks (2006). Hantula et al. (2008) built on ancestral foraging theory to hypothesize and demonstrate empirically that online shoppers' purchases are related to online delays according to a hyperbolic delay function. Saad (2008) used evolutionary psychological findings to infer and show empirically that online female escorts consistently advertise traits that are well aligned with evolved male preferences, including the universal preference for the 0.7 waist-to-hip ratio (Singh & Randall, 2007). Porra & Parks (2006) proposed a broad model of sustainable virtual communities based on the sustainability properties of natural animal colonies, with many interesting contemporary applications (see, also, Porra, 1999 and Porra et al., 2005).

One of the co-authors has recently edited a Springer book titled "Evolutionary psychology and information systems research" (Kock, 2010b). This book is a compilation of chapters written by leading researchers whose common characteristic is having investigated issues at the intersection of the fields of information systems and evolutionary psychology. The book focuses on concepts and theories of evolutionary psychology that can be used as a basis for information systems research; includes several exemplars of evolutionary information systems research in practice; and summarizes emerging issues and debate that can inform evolutionary information systems research. The book also includes debate regarding philosophical foundations and the credibility of related findings.

3. What are the Indications that a Trait has an Evolutionary Basis?

The theoretical discussion presented here assumes that most of the evolved information processing traits possessed by modern humans have been either developed or reinforced (if developed during even earlier evolutionary stages) in what is often referred to as the environment of our evolutionary adaptation (EEA). The EEA is the environment in which most of the evolution of our hominid ancestors took place (Buss, 1999; Cartwright, 2000), from approximately 1.8 million years ago and leading up to the emergence of the human species around 100,000 years ago. From a physical perspective, the EEA had many of the elements that characterize today's African savannas. The EEA is assumed to have been a relatively uniform environment, although not a static one, and significantly different from modern urban environments (Boaz & Almquist, 1997).

Figure 1 illustrates how a trait would have evolved in the EEA via natural or sexual selection. Traits evolve in populations; that is, evolution is a population phenomenon, not an individual phenomenon (Cartwright, 2000; McElreath & Boyd, 2007; Price, 1970). A gene-induced trait appears in a population only if a genotype that codes for the trait appears first. The trait is the physical or mental expression of the genotype; e.g., opposing thumbs, or aggressiveness. For evolution via natural or sexual selection to take place, it is not necessary that all individuals with a genotype express the trait coded for the genotype, but it is necessary that a positive correlation exists between possessing the genotype and expressing the trait (Price, 1970; Rice, 2004). The genotype is a particular combination of alleles (or gene variations) that appears in a population via stochastic processes (Gillespie, 2004; Hartl & Clark, 1997). Once a genotype appears in a population, there are two possible outcomes.

Either the genotype disappears from the population, or it increases in frequency in the population. When the latter outcome occurs, the trait is said to be evolving in the population (Maynard Smith, 1998; Rice, 2004).

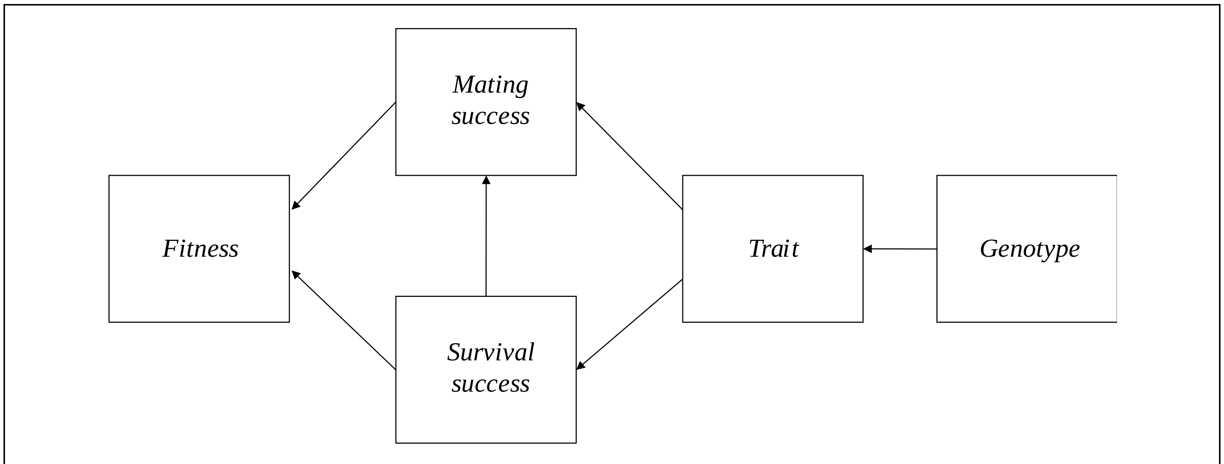


Figure 1. A Gene-Induced Trait Must Have Increased Fitness in the EEA to Have Evolved

For a trait to increase in frequency in a population, it must increase the "fitness" of the individuals that possess it, where fitness is a measure of the reproductive success of those individuals (e.g., number of surviving offspring). Fitness can be increased by the trait increasing the survival and/or mating success of the individuals that possess it (Boaz & Almquist, 1997; Maynard Smith, 1998; Wilson, 2000). An increase in survival success tends to also increase mating success, because an individual typically must be alive to mate.

Investigators in search of evolved human traits usually depart from the assumption that the genotypes that coded for the traits spread to a significant proportion of our ancestors in the EEA (Cartwright, 2000; Wilson, 2000). Therefore, one indication that a trait has an evolutionary basis is that the trait is present in different cultures, which would suggest that the trait could be a human universal (Brown, 1991). Another indication is the existence of a plausible path of causality linking the trait, survival success, and ultimately fitness; without which, the trait would not have evolved (Maynard Smith, 1998; Wilson, 2000). These indications not only provide the basis on which evolutionary traits can be hypothesized to exist, but also the fundamental impetus for the development of the four theoretical principles and related guidelines proposed here.

Hypothesizing an evolutionary basis for a trait is a first step, which must be followed by multiple empirical studies addressing different facets of a phenomenon (or various phenomena) associated with the trait (Kock, 2009, 2010b). This is particularly true for behavioral traits, as our current state of knowledge is limited regarding possible evolutionary bases of such traits. Many behavioral traits that may appear to have been evolved in the EEA could actually be the result of cultural influences; in which case they could be expressed in part, or mostly, due to cultural learning.

That is, even though a trait that is present in different cultures may have an evolutionary basis, it is also possible that the trait in question is the result of behavioral practices that are common among the different cultures and have no genetic basis. In this sense, a behavioral trait being present in different cultures suggests a possible evolutionary basis, and provides a motivation for empirical research, but does not necessarily guarantee that the trait has an evolutionary basis.

4. Panglossian, or Naïve, Evolutionary Theorizing

There are potential obstacles to the realization of the promise that explanations and predictions based on evolved information processing traits may hold for technology-mediated task performance research. Evolutionary psychologists and human evolution researchers have long realized that theorizing about evolved mental traits is very difficult to do in ways that lead to valid testable predictions. Quite often that theorizing leads to what are known as “just so” or “Panglossian” explanations (Buss, 1999; Cartwright, 2000), named after a Voltaire novel’s character called Pangloss who was notorious for being nonsensically naïve about cause-effect relationships. Panglossian explanations may at first glance be seen as valid evolutionary explanations of observable traits, but end up proving wrong and misleading.

We use the term “Panglossian” here as essentially synonymous with “naïve.” The justification for the use of the term “Panglossian” here is that it has become quite common in the field of evolutionary psychology and related fields. It has even been incorporated into widely used textbooks addressing evolutionary psychology issues. Cartwright (2000, p. 40), for example, provides a clear illustration of what a Panglossian explanation is: “Panglossian explanations are fascinating exercises in the use of the creative imagination. Consider why blood is red. It could help make wounds visible, it could indicate the difference between fresh and stale meat and so on. Yet blood is red simply as a consequence of its constituent molecules, for example hemoglobin, and has probably never been exposed to any selective force.”

From a technology behavior perspective, it would be analogously Panglossian to try to explain why flat keyboards are so widely used based on evolutionary thinking. There has been no selective pressure in our evolutionary past in favor of flatness of typing surfaces because typing is a very recent human practice (Kock, 2004); too recent to have shaped the morphology of our hands or brain in any significant way. Moreover, research has suggested that the flat keyboard design is not the best from an ergonomics perspective (Gilad & Harel, 2000), pointing to the explanation that the flat design is so widespread because it is an efficient design from a manufacturing perspective.

Panglossian explanations may also misleadingly assign evolutionary causes to traits that emerged as a by-product of other adaptations, and not directly in response to a targeted evolutionary pressure. This type of adaptation is sometimes referred to as an “exaptation,” or biological “spandrel” (Cartwright, 2000; Gould, 2002). The latter term is the one most commonly used. The term “spandrel” was coined by the late Harvard paleontologist Stephen Jay Gould and the population geneticist Richard Lewontin, inspired by the beautifully and artistically decorated spandrels in Renaissance architecture buildings. These are curved areas that occur between the arches that support a dome, and occur only because of decisions made about the shapes of the arches and dome. That is, even though they seem to be designed for decorative purposes, spandrels exist due to unrelated reasons.

In spite of apparently occurring “by chance,” biological spandrels may refer to traits that characterize, at a very fundamental level, what it means to be human. For example, it has been theorized that the ability to use oral speech for communication is a biological spandrel, most notably by Chomsky (1972, 1993), although this is a topic of continuing debate (see, e.g., Pinker & Jackendoff, 2005).

How can one avoid Panglossian explanations when conducting research on evolved information processing traits and their possible effects on technology-mediated task performance? One alternative is to derive key principles to guide that research based on mathematical formalizations of evolutionary thinking (Grafen, 1990; Hamilton, 1964; Trivers, 2002). In a broader sense, this has led to the development of the field of population genetics (Hartl & Clark, 1997), which mathematically formalized evolutionary notions from a gene-centric perspective. The field of population genetics, pioneered by Fisher (1930), was instrumental in the modern evolutionary synthesis (Mayr & Provine, 1998). It eventually led to the unification of the principal ideas from the theory of evolution by natural selection with the field of genetics, which set the stage for the development of many related subfields, including the field of evolutionary psychology (Barkow et al., 1992; Trivers, 2002).

The term “unification,” as used here referring to the theory of evolution by natural selection and the field of genetics, means expressing the ideas underlying the theory of evolution by natural selection in terms of the laws of discrete genetic inheritance originally proposed by Gregor Mendel (Maynard Smith, 1998). The term “modern evolutionary synthesis” generally refers to the unification of ideas from several specialties within biology, providing a widely accepted account of the evolutionary process (Mayr & Provine, 1998).

In the following section, we develop four principles and related guidelines to serve as a basis for future research on evolved information processing traits and their effects on technology-mediated task performance. We derive the principles and guidelines from mathematical formulations based on two of the most fundamental conceptual tools employed in population genetics and mathematical modeling of evolutionary processes, namely: Fisher's (1930) Fundamental Theorem of Natural Selection; and the Price Equation, named after George Price (1970). We provide an illustration of the application of the principles and related guidelines through a study of information processing enhancement caused by a computer-simulated threat.

5. The Four Research Principles

We present and discuss in this section several mathematical formulations that serve as the basis for the development of four principles for research on evolved information processing traits and their possible impact on technology-mediated task performance. Principle P1 comes fairly directly from Fisher's (1930) Fundamental Theorem of Natural Selection. We develop principles P2, P3, and P4 based on mathematical formulations derived from the Price Equation (Price, 1970). At the end of the section, we provide specific guidelines for investigators conducting theoretical and empirical research following the principles.

5.1. Fisher's Theorem and Principle P1

One of Fisher's (1930) key contributions to the understanding of natural selection from a genetic basis is the Fundamental Theorem of Natural Selection. It essentially equates the rate of increase in fitness of an organism at any given time with the organism's variance in genetic fitness at that time. Variance in genetic fitness is meant as variance in fitness associated with an organism's genes. The higher that variance, the wider is the range of genes that can be expressed, leading to a wide range of phenotypic traits that may be subject to selection. Genetic variability is the main "fuel" that enables the evolutionary process; without genetic variability, there can be no evolution. Actual fitness, or reproductive success, depends on the interaction between genes and environment, a process that shapes the expression of genes in the form of phenotypic traits such as bone density, resistance to disease, and aggressiveness.

Sub-environments in the EEA had different elements (e.g., food resources, climate, and predators) for which different organisms usually were differentially adapted. Compounding the variety of sub-environments in the EEA was the fact that those sub-environments were themselves always changing, even if slightly. For example, changes in climate (e.g., from tropical to subtropical) happening over time would render phenotypic traits evolved to maximize fitness in one climate (tropical) suboptimal in the other climate (subtropical).

Equation (1) highlights in mathematical form one aspect of Fisher's Theorem that is particularly relevant for our discussion. It equates: $\Delta \overline{w}$, which is the variation in mean fitness of a population of organisms at two subsequent points in time; with the term: $\overline{w}' \mid E' - \overline{w} \mid E$, which is the difference between mean fitness in the environments *E'* and *E* at the two subsequent points in time. (The prime symbol indicates the different points in time.) Fitness, indicated as *w*, is the number of surviving offspring of an individual in the population. For elaborate discussions of Fisher's Theorem, its different interpretations, related corollaries, and various theoretical applications see Plutynski (2006) and Price (1972).

$$\Delta \overline{w} = \overline{w}' \mid E' - \overline{w} \mid E \qquad (1)$$

In a relatively stable environment, that is, one in which *E'* and *E* are very similar, the term $\Delta \overline{w}$ would move toward zero in successive generations of a population of individuals as fitness-enhancing traits would spread to all of the individuals of the population through natural selection. While the EEA was not a completely stable environment (Boaz & Almquist, 1997; Cartwright, 2000), many of the information processing traits of modern humans were likely shared by the vast majority of individuals at the end of the EEA (Barkow et al., 1992; Buss, 1999) because of the evolutionary process underlying Equation (1).

The environmental changes that occurred between then (i.e., the end of the EEA) and now were large; many caused by human intervention (e.g., new methods and technologies). Equation 1 suggests that the current level of fitness conferred on modern humans by those information processing traits is also largely different from the level of fitness conferred by the traits at the end of the EEA. Yet, those information processing traits are likely to trigger instincts in modern humans based on actual or perceived similarities between today's environment and the EEA. We tend to crave sweet foods today, for instance, because our ancestors evolved information processing traits to make them associate pleasure with the gustative and visual stimuli linked with those foods (Buss, 1999). The reason is that those foods were relatively difficult to obtain and a target of intra- and inter-specific competition in the EEA, while they were also of high value as a nourishment source due to their nutrition content. In this case, sweetness and visual appeal are associated with nutritional value, two elements that positively influenced survival and reproductive success among our ancestors (Boaz & Almquist, 1997; Cartwright, 2000).

One interesting aspect of evolution highlighted by Equation (1) is that large environmental changes have the potential to lead to equally large differences in fitness. When substantial changes in the environment take place suddenly in evolutionary time—or in less than one hundred generations for various traits and species (Hartl & Clark, 1997)--evolutionary forces may not act quickly enough to shape traits to the new environment. In the case of information processing traits in humans, the outcome would be behavioral responses that are designed to solve problems faced in the EEA. To take advantage of information processing traits existing at the end of the EEA, modern humans could possibly artificially create environments, using advanced computer technologies, for example, that selectively bear similarities with the EEA. This discussion leads to Principle P1:

> **P1**: *There must be perceived similarities between the modern technology-mediated task environment and the EEA.*

The word "perceived" in P1 highlights the fact that evolved information processing traits, by definition, have been "designed" by natural selection to respond to sensorial stimuli that lead to perceptions about an environment, where the perceptions may not reflect very well the actual environment surrounding an individual. The task environment mentioned in P1 includes those environmental elements created by technology, and can even be entirely created by technology. An immersive virtual reality environment is an example of environment entirely created by technology (Briggs, 2002; Kock, 2008).

New technologies have been at the source of the large environmental differences between the end of the EEA and today. Therefore, new technologies, in a sense, create a problem for P1 to be satisfied in modern research on technology-mediated task performance. Nevertheless, it is interesting to note that some of the most recent new technologies, such as those enabling the creation of virtual worlds (Anthes, 2007; Kock, 2008), can also enable the creation of virtual environments where P1 is likely to be satisfied. Virtual worlds can be designed in such a way as to evoke elements of the EEA that can improve technology-mediated task performance; for instance, databases can be designed so that searching for data is similar to foraging for food in a savanna-like environment.

5.2. The Price Equation and the Evolution of Information Processing Traits

The Price Equation (see Equation 2) was developed by Price (1970), and is sometimes referred to as Price's equation or Price's covariance equation (McElreath & Boyd, 2007; Rice, 2004). It has become one of the most widely used mathematical formulations in evolutionary theorizing (Fletcher & Zwick, 2007; Frank, 1995, 1997; Grafen, 2002, 2006; Henrich, 2004; Page & Nowak, 2002; van Veelen, 2005).

$$\bar{w}\,\Delta\bar{x} = Cov(w_i, x_i) + E(w_i \Delta x_i) \qquad (2)$$

The left side of the Price Equation contains the product between $\bar{w}$, which is the mean fitness in a population of individuals at a certain point in time, and $\Delta\bar{x}$, which represents the difference between the average frequency of a quantitative trait present in the population at two different points in time.

The variable x tracks the trait, which can be any evolved information processing trait that has a relationship with fitness in a population of individuals indexed by i. For instance, x could be defined as 1 for individuals with an evolved information processing trait inducing the mental association of a sense of fear with high altitudes (i.e., fear of heights), and 0 for individuals without that fear. Those individuals for whom $x = 1$ would be less likely to fall from high altitudes, since they would avoid high altitudes, and would then survive in higher quantities and likely have more offspring.

In the Price Equation the term $\Delta \bar{x}$ could be represented as $M(x, t_2) - M(x, t_1)$, where t_2 and t_1 refer to two different points in time, and $M(x, t_n)$ is the average frequency of the trait tracked by x at a certain point in time t_n. If this notation were to be used, then $\bar{w}$ could be represented as $M(w, t_1)$. To avoid excessive notation complexity in the steps below, whereby other mathematical formulations will be derived from the Price Equation, we will use the notation in Equation 2 instead.

The right side of the Price Equation contains the sum of $Cov(w_i, x_i)$, which is the covariance between fitness and the evolved trait for all individuals indexed by i of a population, and $E(w_i \Delta x_i)$, which is the expected value of the variation in the trait between two points in time (e.g., through mutation) weighted by the fitness associated with the trait. Equation (2) holds for any variation in traits, as long as fitness is defined as a function of the trait (see, e.g., Frank, 1995).

The main interest here is in the evolution of information processing traits in response to fitness-impairing events where, for each individual of a population of human ancestors: (a) an information processing trait is defined as negatively related with the probability of a fitness-impairing event; and (b) the probability of a fitness-impairing event is negatively related with fitness. In other words, the information processing trait in question should have been evolved by our ancestors in the EEA to reduce the probability of them being involved in a fitness-impairing event. This, in turn, should have increased their fitness and thus spread throughout the species over several generations. This leads to Equation (3).

$$w_i = \alpha + \beta_{we} \beta_{ex} x_i + \varepsilon_i \tag{3}$$

The term α refers to the constant baseline fitness in Equation (3), which expresses w_i as a function of x_i for each individual i of a population. β_{we} is the regression of fitness (w) on the probability of a fitness-impairing event (e), and β_{ex} is the regression of that probability on the trait tracker variable (x). The term ε_i is the uncorrelated error in the linear equation. Applying simple properties of covariance (Kenny, 1979; Mueller, 1996) to Equation 3 leads to Equation 4, where V_x is the variance of the trait tracker variable (x) in a population of individuals indexed by i.

$$Cov(w_i, x_i) = \beta_{we} \beta_{ex} V_x \tag{4}$$

In theoretical developments such as the one conducted here, where the main concern is the evolution of a trait over subsequent generations based on natural selection forces, the term $E(w_i \Delta x_i)$ in the Price Equation is usually set to zero (see, e.g., Frank, 1995; Henrich, 2004). The reason is that the term Δx_i accounts for variation in a trait at the individual level due to forces unrelated to natural selection (e.g., genetic mutation or drift). Moreover, that variation is likely to be extremely small from one generation to the next, and even over many generations, to the point of being often insignificant in the context of the spread of an existing genetic trait in a population. Given this, the combination of equations (2) and (4) leads to Equation 5.

$$\bar{w} \; \Delta \bar{x} = \beta_{we} \beta_{ex} V_x \tag{5}$$

What Equation (5) essentially means, for the purposes of the argument put forth here, is that the variation over time in average frequency of a trait ($\Delta \bar{x}$) in a population is directly proportional to the product of the regression coefficients (β_{we} β_{ex}) on the path linking the trait (x) to fitness (w) and the variance of the trait (V_x) in the population. The mean fitness ($\bar{w}$) must be greater than zero, otherwise the population will quickly become extinct, and any evolved trait will disappear with it. As the trait (x)

evolves, increasing in frequency in the population (a reduction in V_x), the variation over time in average frequency of the trait ($\Delta \bar{x}$) approaches zero. Eventually the trait will reach fixation; that is, it will spread to the entire population. For this evolution toward fixation to take place, the product of the regression coefficients (β_{we} β_{ex}) and the variance of the trait (V_x) in the population must be positive, up until the point of fixation.

5.3. Principles P2, P3 and P4

Equation (5) has some interesting implications, which will, in turn, lead to principles P2, P3, and P4 (stated below). The information processing trait tracked by *x* in Equation (5) will spread throughout the population only if β_{we} β_{ex} $V_x > 0$ because only that will lead to positive increments in the average frequency of the trait $\Delta \bar{x}$ over successive generations. It is expected that $\beta_{we} < 0$ since, by definition, a higher probability of a fitness-impairing event is associated with lower fitness of an individual. Therefore, it should also be the case that $\beta_{ex} < 0$ for β_{we} β_{ex} $V_x > 0$ (by definition, V_x is always non-negative). That is, the increasing presence of an information processing trait in a population should be associated with a reduction in the probability of a fitness-impairing event if the trait has been evolved in response to the fitness-impairing event. Therefore, having both $\beta_{we} < 0$ and $\beta_{ex} < 0$ in the EEA for a particular information processing trait would have made the trait more likely to be found in modern humans, and thus, more likely to be observed in the context of modern technology-mediated tasks. This leads to principles P2 and P3:

> **P2**: *The events that have created selective pressures for the evolution of the information processing trait must have impaired fitness in the EEA.*
>
> **P3**: *The information processing trait must have reduced the probability of a fitness-impairing event in the EEA.*

For example, it has been shown that people generally display enhanced information processing in the temporal vicinity of surprise events of an unpleasant nature, particularly within a window comprising a few minutes after such an event (Brown & Kulik, 1977; Edery-Halpern & Nachson, 2004). This is arguably an evolved information processing trait that allowed our human ancestors to avoid surprise situations of an unpleasant nature in the EEA, because those surprise situations usually involved survival threats – i.e., they were events that impaired fitness (Kock, Chatelain-Jardón, & Carmona, 2008). Examples of unpleasant surprise situations in the EEA are close encounters with dangerous animals and near falls from cliffs. Thus, one can reasonably assume that incorporating surprise events into computer interfaces used for online learning should have an effect on learning effectiveness, arguably a positive one in the temporal vicinity of the surprise events. This is an example of identifying an information processing trait associated with an event that impaired fitness in the EEA (satisfying principles P2 and P3), and tying that to the modern technology-mediated task of online learning.

Another implication from Equation (5) comes from the interpretation of the term V_x, which refers to the variance of the information processing trait in the population. Since the variance associated with any variable is the square of that variable's standard deviation, the term V_x will always be equal to or greater than zero. The term V_x would tend toward zero as the information processing trait spreads within a population of individuals, thus, reducing its variance in the population. Assuming that to have happened in the EEA, it would be reflected today in a low variance in the evolved information processing trait in question among different groups of modern of humans, regardless of cultural and national differences. In other words, evolved information processing traits associated with significant selective pressures found in the EEA are generally expected to be universally observed among modern humans. This implication leads to Principle P4:

> **P4**: *The information processing trait must be a human universal.*

It is important to note that the notion of universality, as used in Principle P4, does not mean identical expression of a trait by all modern humans. The definition of a human universal employed here is the same as Brown's (1991). That is, a human universal is defined as a trait that is observable in all cultures, by the virtue that the majority of the individuals in each culture display the trait in one form or another. In this sense, trade, religion, and fear of snakes are human universals (Brown, 1991).

The value expressed by V_x could only have been reduced to zero for a particular trait if the EEA had been a completely stable environment, if no force other than natural selection operated on the genes leading to the trait, and if the trait was completely determined by our genes. None of these conditions is realistic for the vast majority of human traits, since the EEA was not completely stable (Boaz & Almquist, 1997), there were other forces modifying genes and gene frequencies during the EEA such as genetic mutation and drift (Cartwright, 2000; Gillespie, 2004), and the vast majority of traits are not entirely determined by our genes (Wilson, 2000). The most likely scenario was the retention by our ancestors of a certain amount of variance in connection with virtually all information processing traits at the end of the EEA. That would lead to observable variations in the traits in modern humans, including traits that influence our behavior toward technology, but also observable commonalities.

5.4. Guidelines for Technology-Related Research Following the Principles

Table 1 provides specific guidelines for investigators conducting theoretical and empirical research on technology-mediated task performance following the principles. The guidelines follow directly from the principles and the definitions of the different terms that are mentioned in the principles (see Appendix A). We developed the guidelines so that following at least one proposed for each principle, as opposed to following all the guidelines associated with a given principle, will lead to theoretical and empirical investigations that are aligned with that principle.

We also provide references next to the guidelines. We present the guidelines here as a normative contribution for empirical researchers, and as based primarily on the principles we developed earlier, as opposed to being derived directly from previously published research. Given that, the references provided next to the guidelines should be seen as compatible with the guidelines, and providing additional details related to the guidelines. We add the references for completeness and as sources for further reading.

Table 1. Guidelines for Research Following the Principles

Principle	Guidelines
P1	P1.G1: Incorporate elements in the technology interface that are evocative of the events in the EEA that led to the evolution of the information processing trait; e.g., animal pictures (Kock et al., 2008).
	P1.G2: Focus on technology-mediated tasks with activities that bear similarities to the events in the EEA that led to the evolution of the information processing trait; e.g., web-based foraging (Hantula et al., 2008).
P2	P2.G1: Focus on events that likely led to death among many individuals in the EEA, such as group exposure to highly contagious pathogens (Boaz & Almquist, 1997).
	P2.G2: Focus on events that likely led to death prior to reproductive age in EEA (Hung, 2004).
	P2.G3: Focus on events that likely led to simultaneous death of closely related individuals in the EEA (Hamilton, 1964).
P3	P3.G1: Identify possible information processing traits that likely led to avoidance of fitness-impairing events in the EEA; e.g., fear of heights (Jackson & Cormack, 2008).
	P3.G2: Identify possible information processing traits that likely led to increased chances of survival in fitness-impairing events in the EEA; e.g., reflex reactions in dangerous situations (Schützwohl, 1998).
P4	P4.G1: Focus on information processing traits that are observed in modern humans from different cultural backgrounds in one or more countries (Brown, 1991).
	P4.G2: Focus on information processing traits that are observed in modern humans from countries or country regions that differ significantly in cultural dimensions; e.g., traits variously observed in western and eastern countries (Hofstede, 2001).

The guidelines in Table 1 provide practical research design suggestions for implementation of the principles, and we provide them here to facilitate the use of the principles by researchers interested in conducting theoretical and empirical research on evolved information processing traits and their impact on technology-mediated task performance among modern humans. In the application of P4.G2, one could use a model such as Hofstede's (2001) to assess whether there are significant differences in cultural dimensions among countries and country regions.

It should be noted that the principles are significantly more general than the guidelines provided, and could lead to additional guidelines. Nevertheless, it is expected that the simple set of guidelines provided in Table 1 will serve as a solid basis for most research efforts on technology-mediated task performance following the principles. We also refer researchers interested in applying general evolutionary biology principles to the study of information systems to Kock (2009) for a list of journals, organizations, and conferences dealing with evolution and human behavior issues.

6. Example of an Empirical Study That Implements the Principles

The empirical study discussed in this section is modeled on Kock et al.'s (2008) study, and significantly expands on that study. One of the new elements of this study is a much larger dataset with data from two countries. Another is a new set of analyses, where effects are explored for each individual module (explained later), as well as various possible moderating effects. Kock et al. (2008) restricted their study to only one country, did not investigate individual module effects, and did not explore moderating effects.

This new empirical study examines the phenomenon of surprise-induced memorization, also known as flashbulb memorization, a term coined by Brown & Kulik (1977). This study is aimed at clearly illustrating the application of the principles and related guidelines developed earlier in this paper.

6.1. Flashbulb Memorization

The study's motivation comes from a curious phenomenon known in the cognitive psychology literature as flashbulb memorization (Brown & Kulik, 1977; Edery-Halpern & Nachson, 2004). The phenomenon refers to enhanced information processing in the temporal vicinity of a surprise event, particularly a time window comprising a few minutes after the event. The flashbulb memorization phenomenon usually involves surprise events of an unpleasant nature.

Individuals exposed to such surprise events tend to have enhanced associative memories of contextual information received afterward. For example, an individual who is reading a newspaper article at the backyard of a friend's house and is startled by an approaching snake would, upon recollecting the event later, have particularly vivid memories of the different elements of the backyard (e.g., plants, rocks, and their location) and of the article being read (including its content). This enhanced memorization effect is elicited by the surprise caused by the approaching snake.

6.2. Evolutionary Basis of the Phenomenon

The phenomenon seems to be widespread among humans, occurring in situations involving individuals with different cultural backgrounds and from different countries (Berntsen & Thomsen, 2005; Michelon, Snyder, Buckner, McAvoy, & Zacks, 2003; Schutzwohl & Reisenzein, 1999). This opens the door for the possibility that this enhanced information processing phenomenon has an evolutionary basis. One can reasonably assume that unpleasant surprise events might have been frequently associated with survival threats faced by our ancestors in the EEA, such as attacks by dangerous animals.

In the EEA, like today, most animals that posed a danger to humans presumably lived in specialized habitats that our ancestors would likely enter shortly before (i.e., within a few minutes) the encounter with the animal, and leave shortly afterward, if they survived. The encounter itself might last only a few seconds.

The specialized habitats of dangerous animals, such as snakes, are normally characterized by specific markers such as certain types of vegetation, terrain, and rock formations (Boaz & Almquist, 1997; Wilson, 2000). Therefore, having enhanced memories associating an animal attack with habitat markers seen shortly after the attack would have increased the survival chances of our hominid ancestors, as they would have been consciously and subconsciously alerted to the danger associated with the habitat markers in the future, which would help them avoid a second attack, third, fourth, and so on.

Among dangerous animals, snakes seem to have played a particularly important role in the evolution of humans, owing to the long coexistence of snakes with our hominid ancestors, as well as more ancient primate ancestors (Crockford & Boesch, 2003; Isbell, 2006). There is evidence that snakes frequently preyed on our primate ancestors, which were significantly smaller than modern humans, and that such frequent predator-prey interactions likely led to the evolution of information processing traits that are present in modern humans (Isbell, 2006). Evidence also exists suggesting that snake attacks posed a significant survival threat to not only our primate ancestors but also our hominid ancestors living in the EEA (Wilson, 1998; 2000).

Those attacks also pose a real survival threat today in non-urban human societies, with the majority of the victims being children (Hung, 2004). Events that cause high mortality among children can place particularly strong selective evolutionary pressure in favor of information processing traits that are aimed at helping individuals avoid those events. Those information processing traits may be relatively age-invariant, since they could have evolved in childhood, prior to reproductive ability, and remained with the individuals throughout their lives. This is particularly true in connection with survival threats that affect individuals at any age, such as snake attacks, as humans do not become immune to the toxic effect of snake venom as they age.

The idea that there could be enhanced information processing in the vicinity of snake attacks follows directly from the previous discussion that led to principle P2. In this case, the events that created selective pressures for the evolution of the information processing trait are the snake attacks, which must have impaired fitness in the EEA. The idea also follows directly from the discussion that led to principle P3, as the information processing trait must have reduced the probability of a fitness-impairing event in the EEA.

A hominid ancestor living in the EEA and walking through an area where venomous snakes were prevalent would have been surprised by a snake encounter (see Figure 2). The information processing trait discussed above would have led to enhanced development of mental structures linking the appearance of the snake with the snake’s habitat markers. The mental structures would, in turn, have led to enhanced survival and reproductive success, which would have led the trait to spread to its initial population after its initial appearance, and to other populations through migration and interbreeding. The initial appearance of the trait would have occurred via stochastic processes, as with any other trait (Gillespie, 2004; Maynard Smith, 1998; McElreath & Boyd, 2007).

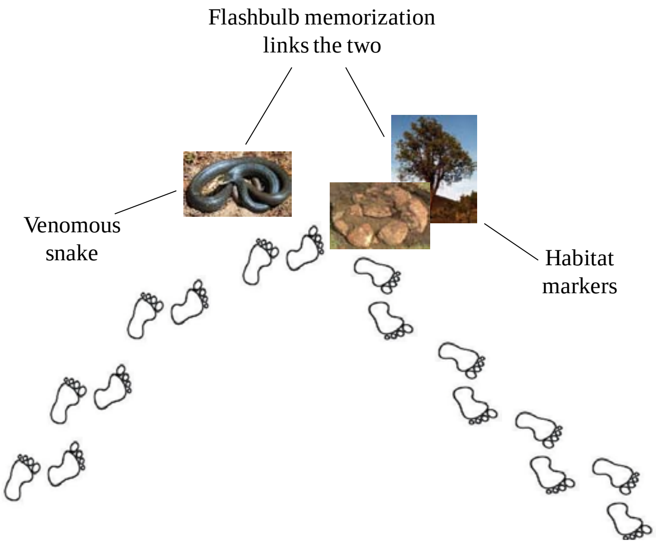


Figure 2. The Evolutionary Basis of the Flashbulb Memorization Phenomenon

The mental association between a snake encounter and habitat markers is a knowledge-type association, as it connects two pieces of information that occur together (Kock, 2004). The fact that snakes are not found just anywhere at random, but rather near their usual habitats, would facilitate the evolution of the related information processing trait. This, of course, assumes that a certain percentage of the individuals involved in snake encounters survived the encounters, and that possessing the trait would make it more likely that an individual would be a survivor. If all individuals involved in snake encounters had died, the trait would not have evolved.

Recalling the previous mathematical discussion, both $\beta_{we} < 0$ and $\beta_{ex} < 0$ would be needed during a certain amount of time for the evolution of such a trait to occur. The amount of time needed would depend on the selective advantage conferred by the trait and the size of the population, and can be estimated based on standard population genetics equations (Hartl & Clark, 1997; Maynard Smith, 1998). Contrary to popular belief, the amount of time needed for such a trait to spread to all individuals in a population would not be in the order of millions of years. Traits can spread relatively quickly. What takes a long time to happen, often millions of years, is the appearance of the right combination of genes and environmental circumstances that can cause a trait to evolve.

Let us assume a population of 10,000 individuals and a new generation emerging every 20 years. Let us also assume that those who possessed the trait would survive in higher numbers, and that would enable them to leave, on average, twice as many surviving children as those who did not possess the trait. In this example, the trait could proceed to fixation in as little as 396 years. Even if the trait conferred a relatively small selective advantage of 1 percent, it could proceed to fixation in 39,614 years.

6.3. The Design of the Study

Following a line of reasoning similar to that outlined above, the researchers predicted that the incorporation of a simulated snake attack into a human-computer interface today would lead to enhanced information processing immediately after the simulated attack. To test this prediction, they developed a number of web-based learning modules, each conveying knowledge regarding a specific topic through six web pages, which a group of individuals reviewed in sequence.

Between two of the modules, a web page with a snake in attack position was shown for a few seconds with the goal of surprising the individuals. The key prediction tested was that the individuals who viewed the snake screen would, on average, obtain higher scores on a test covering the knowledge conveyed through the modules immediately after the snake screen than the individuals who did not see the snake.

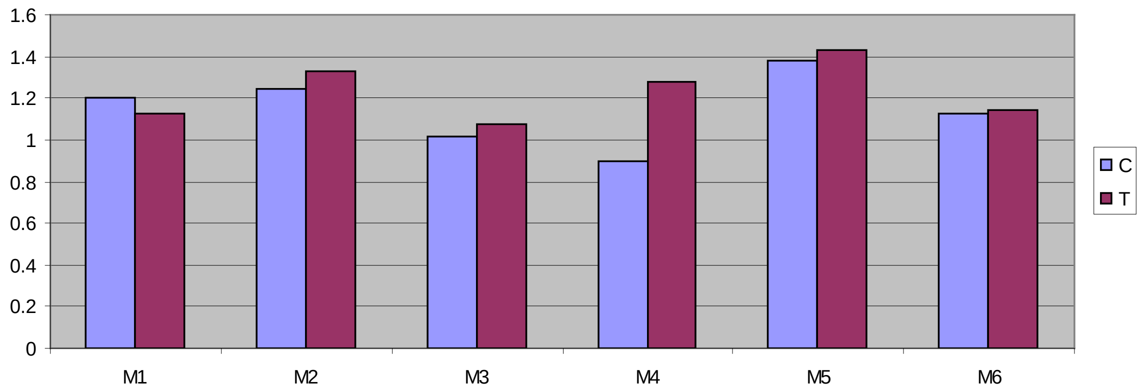
The study involved a total of 370 individuals. Of these, 185 were business students from a mid-sized public university in the southern USA, and the others were business students from a university with similar characteristics in Mexico. The participants were asked to review six learning modules shown as web pages containing only text. The modules were about Incoterms, which are part of a body of standard terminology used in international trade contracts. This term stands for “International Commercial Terms,” which are published by the International Chamber of Commerce (ICC). The individuals’ ages ranged from 19 to 43, with a mean of 23. Approximately 46 percent of the students were males. No individual reported knowing about Incoterms prior to participating in the study.

The researchers employed two experimental conditions, treatment and control. In the treatment condition the individuals were shown a web-based snake screen for 10 seconds between modules 3 and 4. The snake was shown in attack position, together with a hissing background noise (see Appendix B). In the control condition the snake screen was absent; study participants saw only a blank screen for 10 seconds. The researchers obtained Institutional Review Board approval prior to conducting the study, and all participants completed and signed informed consent forms.

Each module’s web page was designed to contain about 265 words (for the content of the modules, see Appendix C), and was shown for 2.35 minutes. The researchers used these specifications in the research design because they characterize the average knowledge communication unit size observed in electronic communication contexts (Kock, 2001). The individuals were randomly assigned to each condition, with approximately half of them in each condition.

6.4. The Main Results of the Study

Figure 3 shows the average scores obtained by the individuals for each module, for both the treatment (snake screen) and control (no snake screen) conditions. The modules are indicated on the X axis as M1, M2, etc., which refer to modules 1, 2, etc. As can be seen, the largest difference in average scores is for Module 4, located immediately after the snake screen in the treatment condition, indicated in the figure as M4.



(T = Treatment Condition, Snake Screen. C = Control Condition, Blank Screen.)

Figure 3. Average Scores Per Module

As can be seen, there were variations in scores across modules that were unrelated to the surprise stimulus. For example, the scores for Module 5 are significantly higher than the scores for Module 3 in both conditions. The reason for this variation is that it is very unlikely that different modules and related questions could have been designed in such a way as to have exactly the same degree of difficulty. In this example, the degree of difficulty for Module 3 is likely higher than for Module 5 (see Appendix C for the content of each of the modules).

The results also highlight the need to have different conditions, treatment and control, in a study like this. One might be tempted to have only one condition, and compare the modules in that single condition. This would probably lead to misleading results and wrong conclusions, as different modules in the same condition may not typically be compared directly with one another. The likely different degrees of difficulty in different modules would add a major confounder to the analysis.

Figure 4 shows the differences in the average scores between conditions, in percentage points, providing a clearer idea of the magnitude of the surprise-induced effect. The modules are indicated on the X axis as M1, M2, etc., which refer to modules 1, 2, etc. The bars were calculated by subtracting the average score for the control condition (the baseline) from the average score for the treatment condition, and dividing the result by the average score for the control condition. This was done for each of the six modules. The largest difference is for Module 4, approaching 40 percent. The differences for the other modules were all below 10 percent.

Table 2 shows the beta coefficients and respective P values obtained through a partial least squares (PLS) analysis with two predictor variables and six criterion variables. The researchers used the WarpPLS 1.0 analysis software (Kock, 2010), selected PLS Regression as the algorithm, and used bootstrapping as the resampling method (Kock, 2010).

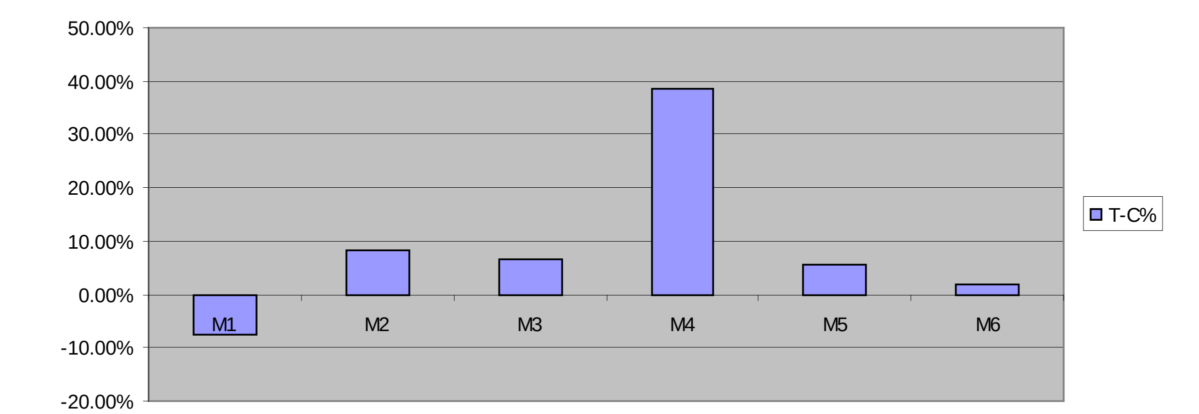


Figure 4. Differences in Average Scores Between Conditions, in Percentage Points

Table 2. Beta Coefficients and P Values for Each Module

Module	β(condition)	P(condition)	β(condition*country)	P(condition*country)
1	-.040	.249	.017	.365
2	.045	.230	.014	.375
3	.037	.238	-.068	.117
4	.215	<.001	.010	.455
5	.037	.263	.090	.059
6	.012	.454	-.002	.475

(Results are for PLS-based comparison of means tests. Predictors: condition = snake screen present or absent; and condition*country = interaction effect between these two variables. Criteria: the six web-based modules.)

There were two main reasons for the use of this type of analysis, namely PLS regression, in this study. These need to be clarified because PLS regression is an advanced multivariate statistical analysis method, and this study is essentially a comparison of means study (Hair, Black, Babin, & Anderson, 2009; Rosenthal & Rosnow, 1991; Spatz, 2010). The first reason is that this type of analysis, PLS regression, does not require the criterion variables to be normally distributed (Chin, 1998; Chin & Todd, 1995). This is relevant in this study because those variables were not all normally distributed. The second reason is that this type of analysis allows for the test of moderating effects, which a standard comparison of means test, even a nonparametric one, would not allow (Rosenthal & Rosnow, 1991; Siegel & Castellan, 1998).

The predictors in the analysis were the categorical variable "condition," with its two categories reflecting a snake screen being present or absent; and the interaction variable "condition*country," which measured the moderating effect of country on the link between the variable condition and each of the criteria. The criteria were the scores obtained by the individual participants for each of the six modules.

The "β(condition)" column shows the standardized coefficients of the regressions of the scores for each module on the predictor variable condition; the "P(condition)" column shows the P values associated with these standardized partial regression coefficients. The "β(condition*country)" and "P(condition*country)" show similar coefficients associated with the moderating effect of the country variable on the link between the variable condition and the scores for the each of the modules.

As can be seen from the values listed in Table 2, only the standardized regression coefficient for Module 4 was significant. That standardized regression coefficient was associated with the variable condition, meaning that the presence of the snake screen only had a significant effect on the scores for Module 4. The effect was highly statistically significant, with a P value lower than .001; the usual threshold for significance in this type of test is .05. The country variable did not have any significant moderating effect, in connection with any module, which means that the strong effect elicited by the snake screen in the scores for Module 4 was not specific to a particular country.

At first glance, one of the P values in connection with the moderating effect of the country variable appears to be close to significant at .059. This is in connection with Module 5. However, closer inspection suggests that the relatively low (but still statistically non-significant) P value is due to the relatively large sample size in this study (370 individuals participated). The corresponding beta coefficient is only .09, suggesting a weak effect size (Chin, Marcolin, & Newsted, 2003). In most statistical tests, P values are sensitive to sample size, decreasing as sample size increases, even as coefficients of association (e.g., beta coefficients) remain constant (Hair et al., 2009). For example, if the sample size were 10,000, the P value in connection with the moderating effect for Module 5 would probably become significant at the .01 level.

Results are also summarized in Appendix D for separate analyses, of the same type discussed above, conducted in the USA and Mexico samples. These results suggest nearly identical major effects. The largest differences by far in average scores, for both the USA and Mexico samples, are for Module 4. These differences were also the most statistically significant. It should be noted that, due to different urban development patterns, in the USA sample snake encounters were likely quite rare, whereas in Mexico they were likely more common (Hung, 2004; Kock et al., 2008).

The results of this study supported the main prediction that information processing would be enhanced immediately after the snake screen. The individuals obtained test scores for Module 4 that were much higher, on average, than in the control condition; the difference was clearly statistically significant. The differences between treatment and control condition scores for the other modules, considering the entire sample, were all statistically non-significant. The fact that the results of the study referring to the major effects (regarding Module 4) were not country-specific provides further support to the evolutionary basis of the phenomenon, as they go some way toward suggesting that the phenomenon is a human universal.

The researchers employed further PLS-based analyses to test for the effects of several possible covariates on the test scores. These were implemented by building links between the possible covariates and the test scores, in the presence of the other predictor and moderating variables. The possible covariates considered were: sex (male or female), age, and scholastic ability (measured by grade point average). No significant covariate effects were found. Based on these analyses it can be concluded that the surprise-induced enhanced information processing effect occurred regardless of sex, age, or scholastic ability.

Finally, the researchers conducted a set of manipulation checks using WarpPLS 1.0 with variables based on question-statements taken from Hofstede (2001). These were done through comparison of means tests designed to assess whether the USA and Mexico samples were representative of their countries. The results of these manipulation checks suggest that the USA and Mexico samples were significantly different from each other, and in a way that was consistent with expectations based on Hofstede’s (2001) framework. The results allow for the conclusion that the USA and Mexico samples were representative of their countries.

6.5. Application of principles and guidelines

The application of the four guiding principles and related guidelines should be conducted in an integrated manner. That is, all of the four guiding principles should be considered at the same time by scholars interested in conducting research on evolved information processing traits and technology-mediated task performance. Since the principles are expressed in general terms, their integrated use is facilitated by the guidelines developed for each principle. Applying the guiding principles and related guidelines is likely to help researchers avoid Panglossian evolutionary theorizing, and also include elements in their research that test effects with a clear evolutionary basis.

The avoidance of Panglossian evolutionary theorizing can be illustrated through an example. Let us assume that a researcher hypothesized that flashbulb memorization had evolved because it allowed ancestral humans to experience excitement, avoiding boredom that could potentially lead to depression and suicide. In this sense, ancestral humans would have enhanced memories of surprise situations so that they could better seek similar situations to incorporate excitement into their lives. This nonsensical hypothesis would be clearly incompatible with Principle P2, which states that the events that have created selective pressures for the evolution of the information processing trait must have impaired fitness in the EEA. The hypothesis would also be incompatible with principles P3 and P4, for related reasons. This would be clear to a researcher even after a cursory review of past research on the lives of Paleolithic humans and modern hunter-gatherers (Boaz & Almquist, 1997; Brown, 1991; Chagnon, 1977; Humboldt, 1995), and its comparison with patterns of modern urban life (Beatty, McCroskey, & Heisel, 1998; Nesse & Williams, 1994; Wilson, 2000). Most of the evidence suggests that the lives of Paleolithic humans and modern hunter-gatherers (prior to becoming “civilized”) were/are somewhat boring (in terms of the range and intensity of emotions experienced on a regular basis) when looked at from the perspective of modern humans living in urban areas, and yet the rates of suicide are dramatically higher among urbanites (Boaz & Almquist, 1997; Nesse & Williams, 1994; Trivers, 2002; Wilson, 2000). Reducing boredom would be unlikely to enhance fitness in the EEA (Principle P2), or reduce the probability of a fitness-impairing event in the EEA (Principle P3). Moreover, the possible boredom-depression-suicide connection is far from being a human universal (Principle P4).

The following example illustrates the usefulness of the principles in forging research elements that clearly build on an evolutionary basis. Let us assume that a researcher hypothesized that flashbulb memorization had evolved for the same reasons stated in the empirical study, namely that unpleasant surprise events might have been frequently associated with survival threats faced by our ancestors in the EEA. But in order to test this hypothesis, let us assume that the researcher decided to surprise the study participants with a screen stating that the computer had a powerful bomb in it that could explode at any second. While this would obviously elicit surprise of an unpleasant nature, it would be incompatible with Principle P1, which states that there must be perceived similarities between the modern technology-mediated task environment and the EEA. Since the surprise stimulus is not evocative of anything that existed in the EEA, as bombs are Neolithic inventions, the research would fail to test effects that clearly have an evolutionary basis.

Table 3 outlines how the four guiding research principles and some of the related guidelines were implemented in the study. Not only does the study implement all of the four principles, it also clearly demonstrates how specific guidelines should be implemented. Moreover, the study provides some empirical evidence that the phenomenon observed is, generally speaking, a human universal; in addition to being designed with that assumption in mind. This is achieved through the two-country data collection, and the analysis of the moderating effect of the variable country on the presence or absence of the phenomenon.

Table 3. How The Principles and Related Guidelines were Implemented in the Study

P / P.G	Implementation in the study
P1 / P1.G1	Incorporated a simulated threat (snake screen) in the technology interface that was evocative of a type of event in the EEA (snake attack) that led to the evolution of an information processing trait.
P2 / P2.G2	Focused on a type of event (snake attack) that likely led to large number of deaths among children in the EEA.
P3 / P3.G1	Identified an information processing trait (surprise-enhanced information processing) that likely led to avoidance of that type of event (snake attack) in the EEA.
P4 / P4.G1	Focused on an information processing trait (surprise-enhanced information processing) that seems to be universally observed in modern humans, regardless of variation in cultural backgrounds.

The empirical study discussed here implemented P1 through P1.G1 by incorporating a simulated threat (snake screen) in the technology interface that was evocative of a type of event in the EEA that led to the evolution of an information processing trait. P2 was implemented through P2.G2 by the study’s focus on a type of event (snake attack) that likely led to a large number of deaths among children in the EEA. The study implemented P3 through P3.G1 by identifying an information processing trait (surprise-enhanced information processing) that likely led to avoidance of that type of event (snake attack) in the EEA.

Finally, the study implemented P4 through P4.G1 by focusing on an information processing trait that seems to be universally observed in modern humans, regardless of variation in cultural backgrounds (Brown, 1991; Brown & Kulik, 1977). It should be noted that this does not mean that the participants in the study represent all humans. That is, the implementation of P4.G1 is reflected in the focus of the study, not in the sample of participants.

7. Limitations

The results of the study might have been different if the participants in the control condition had been shown an image, as opposed to no image. Future studies attempting to replicate the findings of this study should address this limitation. Possible images, in addition to the image of a snake, include: a nonthreatening image evocative of EEA events; a threatening image not evocative of EEA events; and a nonthreatening image not evocative of EEA events. Using other types of images could support the hypotheses of this study, suggest the need for revisions in those hypotheses, or even falsify those hypotheses.

Since the effects hypothesized in the study are assumed to be caused by human universals, a much broader sample would have been needed to fully test the evolutionary basis of the flashbulb memorization phenomenon. As it stands, the study presented here should be seen as an example of the implementation of the principles, rather than a full test of the hypothesized effects. Future empirical studies aimed at replicating the study discussed here should strive to broaden the cultural diversity of the sample, possibly by collecting data from multiple countries.

It is possible that the same participants would have been desensitized to the surprise stimulus after seeing it once. While desensitization would not be inconsistent with the underlying theoretical model, not having tested it is one of the study's limitations that should be addressed in future research. The reason is that desensitization may limit the potential application of the results in practical tasks that involve information processing; e.g., the use of surprise to enhance memorization by airline pilots of procedures associated with emergency situations. A future study could address this limitation by including a second surprise stimulus in the treatment condition and assessing whether the effects on module scores are significantly different from those in the first surprise stimulus. The second surprise stimulus may be the same as the first, or a different surprise stimulus of the same general type, such as a screen that presents a dangerous situation involving an encounter with another animal.

8. Conclusion

This paper potentially makes an important and unique contribution to the research literature on technology-mediated task performance. It does so by proposing an original and parsimonious set of four principles and related guidelines, derived from Fisher's (1930) Fundamental Theorem of Natural Selection and the Price Equation (Price, 1970). These principles and related guidelines provide a useful meta-theoretical framework to guide future theoretical and empirical research on evolved information processing traits and their possible effects on technology-mediated task performance. We offer an illustration of the application of the principles and related guidelines through the analysis of an empirical study of surprise-enhanced information processing in the context of a web-based learning task.

While the empirical study expands on a previously published study, it is still one of the few studies employing evolutionary biology ideas to address a topic that is relevant for the field of information systems. The counterintuitive nature of the empirical study's findings is indicative of one characteristic of applied evolutionary theorizing, in general, and theorizing on evolved information processing traits' effects on technology-mediated task performance, in particular. Such studies tend to unveil phenomena that are not obvious, or self-evident, because evolved instincts often influence behavior at a subconscious level. The study exemplifies an area of inquiry that is only starting to emerge as a legitimate subfield in the broader context of research on technology-mediated task performance.

Further empirical investigations could shed light on new facets of the phenomenon and also complement the empirical study discussed here. The addition of new treatment conditions would be advisable, where some conditions would be evocative of events in the EEA and some would not, and where some would refer to unpleasant events and some would refer to pleasant ones. This would allow researchers to better gauge the degree of connectedness of the phenomenon with its hypothesized evolutionary basis.

Not all traits exhibited by modern humans are the result of evolutionary forces that operated in the EEA. Accordingly, researchers should be cautious about assigning evolutionary causes to behavioral traits. Unfounded evolutionary theorizing can easily derail the potential of the study of evolved information processing traits and their effects on technology-mediated task performance. One of our main goals is to help information systems researchers avoid this, by providing focused and parsimonious guidance to those interested in related investigations.

It is argued here that a large number of possible technology-mediated task phenomena can be theorized and understood based on the framework provided by the principles and related guidelines. One main advantage for researchers using the principles and guidelines is that they will probably avoid naively nonsensical (or Panglossian) hypotheses in their theorizing and empirical investigations. The principles and guidelines serve as a filter for the narrow identification of the kinds of fitness-impairing events that can be reasonably theorized as having led to evolved information processing traits. They also serve as a filter for the narrow identification of the kinds of information processing traits that could have evolved to reduce the probability of fitness-impairing events. Using the principles will arguably add credibility to research on evolved information processing traits and their effects on technology-mediated task performance, and thus advance the field of information systems through a promising path that has scarcely been taken before.

Acknowledgements

This study has been funded in part by a grant from the Office of the Provost at Texas A&M International University. The authors would like to thank Jesus Carmona for his invaluable help in the collection and compilation of the data used in the empirical study. Thanks are also due to Jeff Brown, Chris Ferguson, and Fernando Quintana; for their comments on a previous version of this article. A special thank you goes to Fernando Quintana for enlightening discussions on the basic principles and mathematics of evolutionary biology. All errors and omissions are the sole responsibility of the authors.

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Appendices

Appendix A. Terms and Definitions

Environment of our evolutionary adaptation (EEA): The environment in which most of the evolution of our hominid ancestors took place, leading up to the emergence of the human species around 100,000 years ago. That evolution is believed to have taken place largely in an environment similar to today's African savannas. The EEA is assumed to have been relatively uniform, although not static, and significantly different from modern urban environments.

Evolved information processing trait tracker (x_i): Numeric variable tracking the presence or absence in an individual *i* of one of more alleles (i.e., gene variations) that code for an information processing trait. For example, x_i could be set to 1 for an individual possessing the alleles associated with an information processing trait, and 0 for an individual not possessing the alleles. The tracker is independent of how the coding takes place, and thus, can be associated with any number of related genes occurring in different chromosome loci coding for particular information processing traits. Most information processing traits are associated with multiple genes, which may occur in different loci.

Evolved information processing trait: A mental trait, associated with the processing of information that reaches our senses, which has been evolved through natural selection in response to one or more fitness-impairing events. Information can reach our senses through visual, auditory, olfactory, tactile, and gustative stimuli.

Exaptation: See "spandrel."

Fitness (w_i): The number of surviving offspring of an individual ***i***. This operational definition of fitness focuses on natural selection forces and assumes that the individual's genotype is transferred at least in part to the offspring. Such transfer would also likely lead to a percentage of the offspring inheriting the parent's information processing traits.

Fitness-impairing event: Event involving our hominid ancestors that was likely to cause a reduction in those ancestors' reproductive success (i.e., fitness). The event is assumed to have occurred regularly in the environment of our evolutionary adaptation (EEA). Examples of those events are falls from high altitudes, encounters with dangerous animals, exposure to pathogens, and consumption of fewer calories than needed in a meal.

Fixation of a trait: Point at which all members of a population display a trait evolved through natural selection. A trait will usually appear in a population through a genetic mutation, in one single individual. If the trait confers a selective advantage to the individual that possesses it, it may evolve to fixation in the population. This process may be stopped by chance alone, especially at its initial stages of evolution. For example, the members of a family who share a mutation that enhances their resistance to viral infections may accidentally fall off a cliff and die, all at once.

Panglossian evolutionary explanations: Naïvely nonsensical explanations, which may at first glance be seen as valid evolutionary explanations of observable traits, but end up proving wrong and misleading. They are named after a Voltaire novel's character called Pangloss, who was notorious for being nonsensically naïve about cause-effect relationships.

Probability of a fitness-impairing event (e_i): The likelihood that a hominid ancestor *i* would be involved in a fitness-impairing event e_i at a given point in time. Our ancestors in the EEA likely faced many fitness-impairing events on a daily basis. The probability of occurrence of a fitness-impairing event could have been reduced by evolved information processing traits. One example would be the enhanced memorization of physical elements (e.g., vegetation and rock formations) and their mental association with certain dangerous situations (e.g., snake attacks). This would help our ancestors avoid those situations after they were encountered for the first time.

Spandrel (or biological spandrel): Term coined by the late Harvard paleontologist Stephen Jay Gould and the population geneticist Richard Lewontin, inspired by the beautifully and artistically decorated spandrels in Renaissance architecture. It refers to an adaptation that first evolves in response to a targeted evolutionary pressure, and later undergoes transformations so that it can be used for a different purpose. Architectural spandrels are the curved areas between the arches that support a dome, and occur only because of decisions made about the shape of the arches and the form of the dome. That is, even though they seem to be designed for decorative purposes, spandrels exist due to unrelated reasons.

Technology-mediated task performance: Performance on a given technology-mediated task, measured by task outcomes. One example is that of a technology-mediated learning task where an individual learns about a specific topic using a particular technology. The performance in this task can be measured through a test covering the topic, administered after the task is completed.

Appendix B. Web-Based Modules and the Snake Screen

Six web-based modules on Incoterms were shown in sequence. The learning modules were essentially text-based screens viewed on a web browser. In the treatment condition the individuals were shown a web-based snake screen for 10 seconds between modules 3 and 4; the snake was shown in attack position and with a hissing background noise. In the control condition the snake screen was absent; only a blank screen was shown, also for 10 seconds.

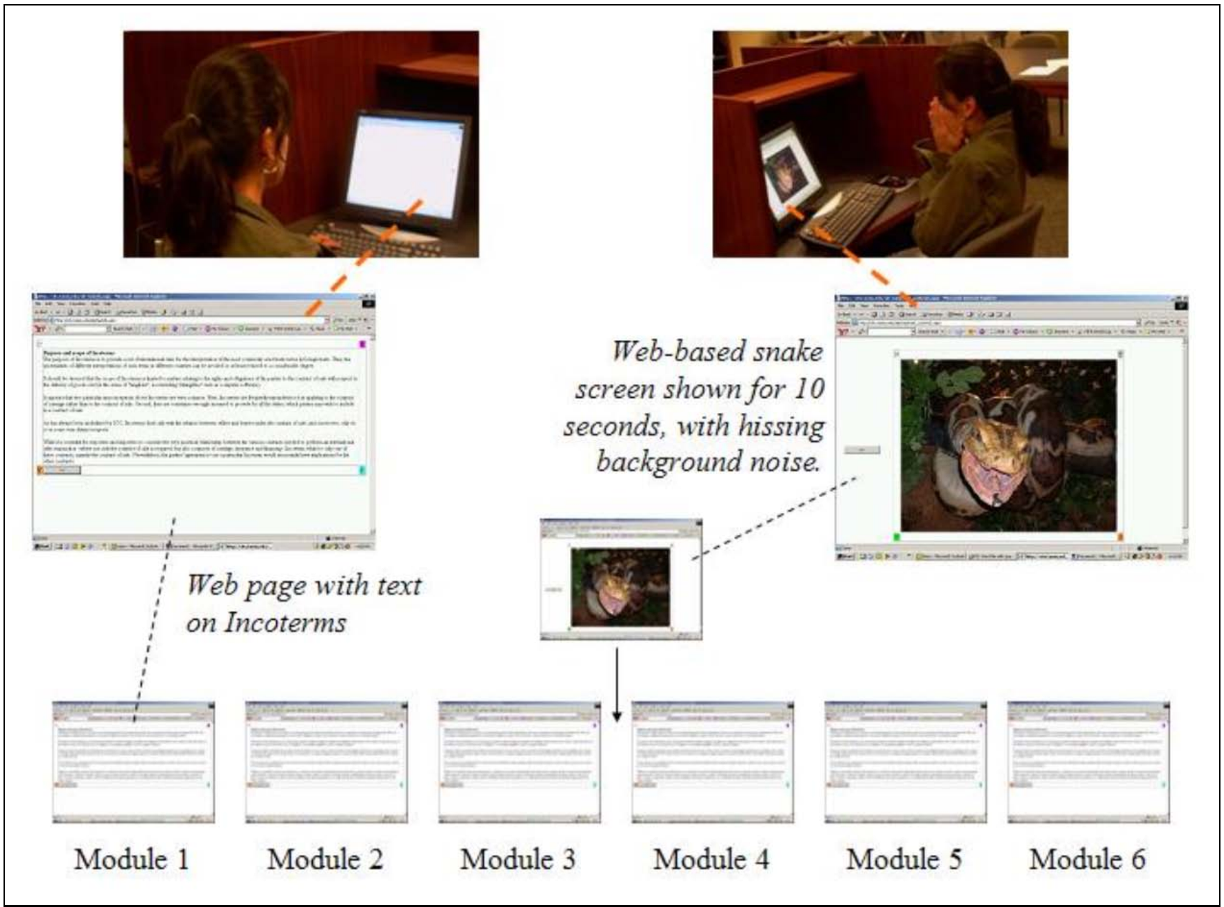

Exhibit B-1. Web-Based Modules and the Snake Screen

Appendix C. Content of the Modules

Below is the content of each of the learning modules used in the empirical study. The modules are about Incoterms, which are part of a body of standard terminology used in international trade contracts. No participant reported knowing about Incoterms prior to the study.

Module 1

The global economy has given businesses broader access than ever before to markets all over the world. Goods are sold in more countries, in larger quantities, and in greater variety. But as the volume and complexity of international sales increase, so do possibilities for misunderstandings and costly disputes when sales contracts are not adequately drafted.

Incoterms, the official International Chamber of Commerce (ICC) rules for the interpretation of trade terms, facilitate the conduct of international trade. Reference to Incoterms 2000 in a sales contract defines clearly the parties' respective obligations and reduces the risk of legal complications.

Since the creation of Incoterms by ICC in 1936, this undisputed worldwide contractual standard has been regularly updated to keep pace with the development of international trade. Incoterms 2000 take account of the recent spread of customs-free zones, the increased use of electronic communications in business transactions, and changes in transport practices. Incoterms 2000 offer a simpler and clearer presentation of the 13 definitions, all of which have been revised.

Frequently, parties to a contract are unaware of the different trading practices in their respective countries. This can give rise to misunderstandings, disputes and litigation, with all the waste of time and money that this entails. In order to remedy these problems, the International Chamber of Commerce first published in 1936 a set of international rules for the interpretation of trade terms. These rules were known as "Incoterms 1936". Amendments and additions were later made in 1953,1967,1976,1980,1990 and presently in 2000 in order to bring the rules in line with current international trade practices.

Module 2

The purpose of Incoterms is to provide a set of international rules for the interpretation of the most commonly used trade terms in foreign trade. Thus, the uncertainties of different interpretations of such terms in different countries can be avoided or at least reduced to a considerable degree.

It should be stressed that the scope of Incoterms is limited to matters relating to the rights and obligations of the parties to the contract of sale with respect to the delivery of goods sold (in the sense of "tangibles", not including "intangibles" such as computer software).

It appears that two particular misconceptions about Incoterms are very common. First, Incoterms are frequently misunderstood as applying to the contract of carriage rather than to the contract of sale. Second, they are sometimes wrongly assumed to provide for all the duties, which parties may wish to include in a contract of sale.

As has always been underlined by ICC, Incoterms deal only with the relation between sellers and buyers under the contract of sale, and, moreover, only do so in some very distinct respects.

While it is essential for exporters and importers to consider the very practical relationship between the various contracts needed to perform an international sales transaction -where not only the contract of sale is required, but also contracts of carriage, insurance and financing- Incoterms relate to only one of these contracts, namely the contract of sale. Nevertheless, the parties' agreement to use a particular Incoterm would necessarily have implications for the other contracts.

Module 3

The Incoterms are divided in four groups based on their arrangement. Departure is the base for group E, main carriage unpaid is the base for group F, main carriage paid is the base for group C, and arrival is the base for group D.

Group E is formed by: EXW - Ex Works (... named place). The Incoterms embraced by group F are: FCA - Free Carrier (... named place), FAS - Free Alongside Ship (... named port of shipment), and FOB - Free On Board (... named port of shipment). Group C is formed by: CFR - Cost and Freight (... named port of destination), CIF - Cost, Insurance and Freight (... named port of destination), CPT - Carriage Paid To (... named place of destination), and CIP - Carriage and Insurance Paid To (... named place of destination). Finally, group D is formed by: DAF - Delivered At Frontier (... named place), DES - Delivered Ex Ship (... named port of destination), DEQ - Delivered Ex Quay (... named port of destination), DDU - Delivered Duty Unpaid (... named place of destination), and DDP - Delivered Duty Paid (... named place of destination).

Not all the Incoterms 2000 are appropriate for all modes of transportation. They are six that must be used exclusively when the transport is maritime and/or inland waterway. These Incoterms are FAS, FOB (group F), CFR, CIF (group C), DES and DEQ (group D). On the other hand, EXW (group E), FCA (group F), CPT, CIP (group C), DAF, DDU and DDP (group D) are appropriate for any mode of transportation.

Module 4

The risk of loss of or damage to the goods, as well as the obligation to bear the costs relating to the goods, passes from the seller to the buyer when the seller has fulfilled his obligation to deliver the goods. Since the buyer should not be given the possibility to delay the passing of the risk and costs, all terms stipulate that the passing of risk and costs may occur even before delivery, if the buyer does not take delivery as agreed or fails to give such instructions (with respect to time for shipment and/or place for delivery) as the seller may require in order to fulfill his obligation to deliver the goods. It is a requirement for such premature passing of risk and costs that the goods have been identified as intended for the buyer or, as is stipulated in the terms, set aside for him (appropriation).

The "E"-term requires the seller to do no more than place the goods at the disposal of the buyer at the agreed place -usually at the seller's own premises.

The "F”-terms require the seller to deliver the goods for carriage as instructed by the buyer.

The "C"-terms require the seller to contract for carriage on usual terms at his own expense. Therefore, a point up to which he would have to pay transport costs must necessarily be indicated after the respective "C"-term.

The "D"-terms require the seller to be responsible for the arrival of the goods at the agreed place or point of destination at the border or within the country of import.

Module 5

"Ex works" means that the seller delivers when he places the goods at the disposal of the buyer at the seller's premises or another named place (i.e. works, factory, warehouse, etc.) not cleared for export and not loaded on any collecting vehicle. This term thus represents the minimum obligation for the seller, and the buyer has to bear all costs and risks involved in taking the goods from the seller's premises. However, if the parties wish the seller to be responsible for the loading of the goods on departure and to bear the risks and all the costs of such loading, this should be made clear by adding explicit wording to this effect in the contract of sale.

The seller must provide the goods and the commercial invoice, or its equivalent electronic message, in conformity with the contract of sale and any other evidence of conformity, which may be required by the contract. The seller must render the buyer, at the latter's request, risk and expense, every assistance in obtaining, where applicable, any export license or other official authorization necessary for the export of the goods. The buyer must pay the price as provided in the contract of sale. The buyer must bear all risks of loss of or damage to the goods from the time they have been delivered in accordance with the term’s delivery; and from the agreed date or the expiry date of any period fixed for taking delivery which arise because he fails to give notice in accordance with the notice of the seller, provided.

Module 6

"Free Carrier" means that the seller delivers the goods, cleared for export, to the carrier nominated by the buyer at the named place. It should be noted that the chosen place of delivery has an impact on the obligations of loading and unloading the goods at that place. If delivery occurs at the seller's premises, the seller is responsible for loading. If delivery occurs at any other place, the seller is not responsible for unloading. This term may be used irrespective of the mode of transport, including multi-modal transport.

"Carrier" means any person who, in a contract of carriage, undertakes to perform or to procure the performance of transport by rail, road, air, sea, inland waterway or by a combination of such modes. If the buyer nominates a person other than a carrier to receive the goods, the seller is deemed to have fulfilled his obligation to deliver the goods when they are delivered to that person.

The delivery is completed: a) If the named place is the seller's premises, when the goods have been loaded on the means of transport provided by the carrier nominated by the buyer or another person acting on his behalf; b) If the named place is anywhere other than a), when the goods are placed at the disposal of the carrier or another person nominated by the buyer, or chosen by the seller in accordance with the contract of carriage, on the seller's means of transport not unloaded.

If no specific point has been agreed within the named place, and if there are several points available, the seller may select the point at the place of delivery which best suits his purpose.

Appendix D. Separate Results for the USA and Mexico

The results below are for PLS-based comparison of means tests conducted separately for the USA and Mexico samples. The tests were conducted with WarpPLS 1.0. They are expressed in beta coefficients and P values for each module. The predictor was the treatment condition, namely snake screen present or absent. The criteria were the scores for each of the six web-based modules. Cells containing statistically significant coefficients at the P<.01 level are darkly shaded, and at the P<.05 level are lightly shaded.

Exhibit D-1. Separate Results for the USA and Mexico

Module	β(USA)	P(USA)	β(Mexico)	P(Mexico)
1	-.048	.270	-.013	.460
2	.020	.467	.047	.254
3	.122	.049	-.023	.380
4	.213	<.001	.233	.001
5	-.051	.186	.127	.029
6	.024	.384	.022	.416

The results summarized above suggest nearly identical major effects and different minor effects. The largest differences by far in average scores, for both the USA and Mexico samples, are for Module 4. This module was located immediately after the snake screen in the treatment condition. These differences were also the most statistically significant, and represent the similar major effects.

In the USA the difference in average scores for Module 3 was also significant, whereas in Mexico the difference for Module 5 was significant (both at the P<.05 level). These are the different minor effects. Since memories related to Module 3 were fading but not completely erased when the participants were surprised, this may explain the USA result. The result for the Mexico sample may be due to a ripple effect, extending beyond Module 4 and into Module 5.

The differences in the minor effects in the USA and Mexico do not falsify the hypothesized evolutionary basis for the phenomenon, but suggest that certain country-specific differences may have small moderating effects on it. These moderating effects are said to be small because none was detected through the more targeted moderating effect analysis conducted on the entire sample, and discussed on the main body of the paper. Further research is needed to clarify the nature of these possible small moderating effects.

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