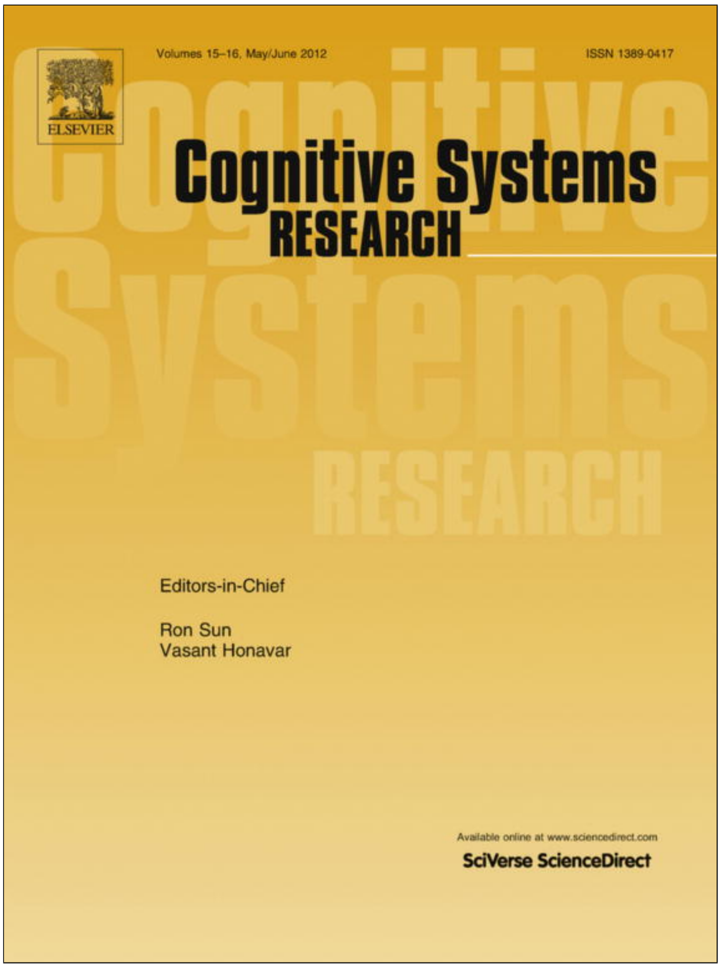
Volumes 15–16, May/June 2012
ISSN 1389-0417
ELSEVIER
Cognitive Systems
RESEARCH
Editors-in-Chief
Ron Sun
Vasant Honavar
Available online at www.sciencedirect.com
SciVerse ScienceDirect

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Cognitive Systems Research 15–16 (2012) 50–56

Cognitive Systems Research

www.elsevier.com/locate/cogsys

Who is in charge of science: Men view "Time" as more fixed, "Reality" as less real, and "Order" as less ordered

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Received 11 May 2011; accepted 15 June 2011
Available online 21 July 2011

Abstract

There is a controversy about the factors underlying male predominance in mathematics, natural and engineering sciences. Our study of meaning attribution, conducted in Canada, China and Russia showed that men had a consistent tendency to estimate natural phenomena (even time-related) as more fixed and limited, less real (even "Reality") and less complex (even "Complexity") than women. Concepts related to classical mechanics received significantly more positive estimations by men than by women, but phenomena related to development and reality were assessed more positively by women than by men. We argue that the methods and language of science, which historically were developed by men, were affected by a tendency of men to reduce natural phenomena to structures with Lego-like components, and to mechanical aspects of their interaction.

Keywords: Meaning attribution; Sex differences; Language of science

1. Introduction

In 2008 the journal Science published 1168 articles (including Bre Nonlinear Dynamics, Psychology, and Life Sciences handy for the years 2007–2010 via, Perspectives, Research articles, Reports and some Letters) presented by 6627 authors,[1] 84% (5544) male and 16% (1083) female. The sex ratio for 146 single authors was even worse: M/F = 90.5/9.5%. The ratio of male/female authors published between 1978 and 2007 in the journal Behavioral and Brain Sciences was no better: 85/15%, with a ratio of 91/9% for single authors. For the journal Nonlinear Dynamics, Psychology, and Life Sciences from 2007–2010 this ratio was 76/24% for all authors, and 78/21% for single authors. Debates about the causes of male predominance in the natural sciences commonly point to social factors, such as job arrangements, competition, and social expectations (Halpern et al., 2007), and to biological factors, namely abilities assessed by the Scholastic Assessment Test required for admission to universities, in which men consistently show better scores (Levy & Kimura, 2009; Wainer & Steinberg, 1992). We fully agree with concerns related to these social and biological factors, however, much less attention in such debates has been paid to a possible bias in the language and methods of these sciences, potentially leading to a bias in the aptitude tests used as a passing card to science. Analysis of the nature of methods assessing reasoning abilities revealed that these methods use primarily one kind of reasoning, and overlook other types of problem solving and decision making (semantic, pragmatic, verbal, intuitive, etc.), which can be equally efficient (Gardner, 1983; Sternberg, 1985).

The fact is that historically the notations, descriptors, logics, presentation of findings and overall language of

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[1] In this count we excluded four reports, which have an unusual for a 3-page scientific publication number of authors (71, 72, 131 and 183).

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doi:10.1016/j.cogsys.2011.07.001

mathematics, physics and other natural sciences were created and designed by men. Coincidently, talented men, when given a choice, have less interest in the life and social sciences, where mechanical reasoning is less applicable (Levy & Kimura, 2009), but talented women do not mind dealing with the life sciences, which have rather fuzzy, fluid and "messy, in terms of variables" objects. This is consistent with findings that in communication men have a tendency to use language in a more instrumental way, choosing object-oriented descriptors while women use more words related to social processes (Newman, Groom, Handelman, & Pennebaker, 2008). It is also consistent with male superiority in mechanical reasoning and their predominance in engineering, physics, and with the larger percentage of women in the life and social sciences than in other sciences. This means that if men differ from women in the way that they conceptualize natural phenomena, then the male style of conceptualization might affect the language of those men-made sciences. Thus, are there any sex differences in scientific conceptualization? Extensive studies of sex differences were primarily focused on observable behavior and found men's superiority in the tasks requiring mechanical reasoning, geometric and spatial (mental rotation) and women's superiority in verbal tasks and calculation (Kimura, 1999). These studies however did not look for the sex differences in on internal psychological processes of concept development or meaning attribution, which were the main focus of our study.

A common way to extract the internal frame of thoughts of an individual is to use projective methods, using material of very general nature, which is open to individual interpretation. Projective Semantics (Trofimova, 1999), based on Osgood's Semantic Differential method, asks people to estimate well-known general concepts using common adjectives in the form of bipolar scales. In using thousands of such scales in 24 languages and with application of factor analysis, Osgood found that these scales had a tendency to group into factors, which showed a remarkable similarity across all tested cultures and even different educational levels, in spite of a large spectrum of meanings and categories which humans use in the interpretation of concepts (Osgood, 1975). The three main factors were called "Evaluation" (which included, for example, the scales "pleasant–irritating", "clear–dirty," "kind–cruel"), "Activity" ("energetic–constrained", "monotonous–keen", "fast–slow") and "Potency", or "Power" ("strong–weak", "firm–flimsy", "massive–miniature"). The universality of these three "dimensions of semantic perception" gained a lot of interest in psychology, followed by the finding of a few additional dimensions: "Typicality", or "Probability" ("typical–exclusive", "regular–rare") (Bentler & La Voie, 1972; Trofimova, 1999), "Improvement", or "Organization" ("organized–non-organized", "regular–spasmodic" "constant–changeable", "precise–indefinite"), "Reality" ("imaginary–real", "evident–fantastic", "abstract–concrete"), "Complexity" ("complex–simple", "mysterious–usual", "unlimited–limited"), Stimulation ("interesting–boring", "trivial–new"), (Rosch, 1978; Petrenko, 1993; Trofimova, 1999) and others.

The Projective Semantic method uses 60 6-point bipolar scales associated to the seven factors which were most consistently found in reports of semantic spaces: "Stimulation", "Evaluation", "Power", "Complexity", "Reality–Probability", "Organization" and "Stability–Limitation".[2] The "objects" of estimations are the abstract concepts of a most general nature, which have minimal dependence on training, personal or gender-specific experience. These concepts are chosen to correspond to the seven named groups (factors) of scales in order to improve the universality of the method and its sensitivity to any bias in responses. For example, the concepts "Reality", "Present" are expected to be assessed unequivocally as "very real" on the scales of the Reality factor, the concepts "Complexity", "Chaos" as "very complex" along the scales of the Complexity factor, the concept "Beauty" is expected to be on the positive pole on the Evaluation scales, "Order" – on the positive pole of the scales of the Organization factor, etc. It is expected that a deformation of this symmetric matrix would reveal underlying biases of two types: in either using certain scales or/and in assessment of certain concepts.

In summary, science progressed with the development of concepts describing abstract properties of natural phenomena, but these concepts still did not emerge "out of thin air": they were rooted in human functional activities and in human interactions with these phenomena. It is well-known in psychosemantics (i.e. science of meaning attribution) that socio-cultural, educational, and personal factors do contribute to the conceptual maps of an individual. The main idea of our experiment therefore was to neutralize these factors, leaving only the sex of an individual as a factor, and to investigate the presence of any sex bias in very basic concepts and conceptual adjectives, which are the most common in all cultures, and which reflect early abstractions of natural and humanitarian sciences.

2. Method

2.1. Samples

Undergraduate psychology students and volunteers (12–15% in each sample), Canadians (N = 797, aged 17–52, including men: $N = 312$, $M_{age} \pm SD = 22.0 \pm 7.4$; women $N = 485$, $M_{age} \pm SD = 20.30 \pm 4.4$, McMaster University, Hamilton, Ontario), Chinese ($N = 206$, aged 17–54, including men: $N = 78$, $M_{age} \pm SD = 25.85 \pm 9.7$; women $N = 128$, $M_{age} \pm SD = 24.57 \pm 8.6$, Guangzhou Pearl River Piano Group Co., Ltd. and Guang Ya School, Guangzhou city, China) and Russians ($N = 119$, aged 17–55, including men: $N = 46$, $M_{age} \pm SD = 23.52 \pm 10.8$; women $N = 73$, $M_{age} \pm SD = 21.70 \pm 9.47$, Moscow State

[2] The opposite pole of the "Activity" factor.

Table 1
The list of bipolar scales (grouped into 7 factors) and concepts. The poles of the scales and the order of the scales and concepts randomly changed between subjects during the experiment.

+ pole – pole	Scales: + pole – pole	+ pole – pole	Concepts:
"***Stimulation***"	Deep-superficial	"***Organization***"	Past
	Powerful-weak		Present
Original-trivial	Leading-following	Clear-blurred	Future
Exciting-indifferent	Significant-insignificant	Obvious-obscure	Time
Bright-pale	Independent-dependent	Regular-irregular	Speed
Stimulating-draining	"***Complexity***"	Rational-irrational	Motion
Interesting-uninteresting		Justified-senseless	Activity
Unusual-ordinary	Continuous-discrete	Reliable-unreliable	Development
Arouses-calms	Multi-dimensional-one-	Precise-imprecise	Reality
Sharp-dull	dimensional	Organized-unorganized	Life
"***Evaluation***"	Chaotic-ordered	Planned-spontaneous	Power
	Diverse-uniform	"***Stability/Limitation***"	Complexity
Pleasant-irritating	Irreplaceable-replaceable		Chaos
Kind-severe	Complex-simple	Steady-faltering	Simplicity
Progress-decline	Inexplicable-understandable	Constant-changeable	Order
Light-dark	Difficult-easy	Slow-fast	
Pure(clean)-dirty	"***Reality/probability***"	Fixed-flowing	
Good-bad		Restrained-unrestrained	
Mine-not mine	Natural-artificial	Dense-scattered	
Useful-harmful	True-false	Limited-boundless	
Soft-rigid	Existent-imagined	Finite-infinite	
"***Power***"	Real-imaginary	Solid-fragile	
	Possible-impossible		
Massive-delicate	Known-unknown		
Rough-smooth	Inevitable-improbable		
Large-small	Typical-atypical		
	Common-rare		

Social University, Russia). All participants were citizens of their corresponding countries, being fluent in the language of the presented material.

2.2. The Semantic Task experiment

All participants went through debriefing and signed consent for participation in the experiment, which was conducted in 1999–2006. The material went through 3 stages of back-forward translation to have exact correspondence between English, Chinese and Russian versions. The experiment used 60 6-point bipolar scales to estimate the 15 general concepts chosen according to the Projective Semantic method (Table 1).[3] Each concept was presented by the program "Expan" on a computer monitor at the top of the screen along with each of the bipolar evaluating scales placed horizontally at the middle of the screen (i.e. 900 screens were presented for the estimation). Both poles of the scales had 3 degrees of freedom ("strongly", "somewhat", "weakly"). For example, the scale warm–cold would read: "strongly warm", "somewhat warm", "weakly warm", "weakly cold", "somewhat cold", "strongly cold". Factor analysis of the data confirmed the affiliation of the listed scales to seven factors (see Table 2 for eigenvalues; factors explained 42.08% of variance in Canadian sample, 42.36% in Chinese sample and 39.09% in Russian sample). University students received a practicum credit for their participation. The order of scales and concepts was changed for each protocol to avoid the consecutive use of several scales related to one factor. This allowed to minimize the multiple comparisons limitations, and therefore no criteria for multiple comparisons were applied. Sex differences in estimations were assessed with the Mann–Whitney U test.[4]

3. Results

In spite of cross-cultural differences in the pattern of responses (Russian men had a strong tendency to perceive the concepts in more negative terms than women[5]) we found sex differences in estimations, consistent across two or all three cultures. Fig. 1 shows stacked columns representing the number of statistically significant sex differences, with colors representing seven factors to which the scales are associated (see Tables S1–S3 in the supporting information available on-line for details). The sign on the axis *Y* indicates the pole of the scales chosen by men for the given concepts. Women's choices are symmetrically

[3] The Russian and Chinese version of the word "Force", which was used in this experiment, has a double meaning of "Force" and "Power".

[4] The sex difference were assessed first for each concept separately and then with this grouping of the concepts based on a cluster analysis.

[5] Russian "nihilism" might be due to the high rate of depression in Russia: in 2004 the World Health Organization reported that suicide rates in Russia are double that of Western countries.

Table 2
Statistics related to factor analysis of used bipolar adjectives (for the grouping of the scales see Table 1).

	Canadians		Chinese		Russians	
Factor	Eigenvalue	% total var.	Eigenvalue	% total var.	Eigenvalue	% total var.
Stimulation	5.49	9.15	1.91	3.53	9.94	14.83
Evaluation	3.35	5.59	9.09	16.83	2.95	4.41
Power	1.75	2.91	2.57	4.75	5.47	8.17
Complexity	1.34	2.23	4.23	7.84	2.03	3.03
Reality–Probability	1.62	2.69	1.67	3.09	1.67	2.49
Organization	10.44	17.39	1.42	2.63	2.30	3.43
Stability-Limitation	1.27	2.12	1.99	3.69	1.83	2.73

the opposite of the illustrated poles. For example, if the Figure shows a Complexity factor in the positive range, it means that men saw the given concepts as more complex, while women saw it as more simple.

We found that men interpreted time progression (Past, Future, Time, Motion, Speed, Activity and Development) as something more slow, constant, finite, dense, limited, restrained, solid and steady than women in all three samples, while women saw it as more fast, changeable, infinite, scattered, unrestrained, fragile and faltering. This tendency was also common in estimations of other phenomena. "Activity" and "Development received more negative estimations among men than among women in Canadian and Russian samples, and were perceived as something less organized and ordered by men than by women in all three samples.

Men estimated "Reality", "Life", "Past", "Future", "Order" and "Simplicity" in more negative terms than women in all three samples, i.e. men saw them as significantly more pale, uninteresting, dark, dirty, small, weak, insignificant, uniform, simple, one-dimensional, easy, replaceable, imaginary, rare, impossible, imprecise, spontaneous, limited and finite, while women estimated them as more bright, interesting, light, clean, large, strong, significant, diverse, complex, multi-dimensional, difficult, irreplaceable, real, common, possible, precise, planned, boundless and infinite. "Order" and "Simplicity" were perceived as less ordered by men than by women, i.e. men consistently estimated the order-related concepts as more irregular, unorganized, imprecise, and spontaneous while women estimated them as more regular, organized, planned and precise. In terms of a bias in using the scales of the Reality factor men perceived practically all presented constructs (except Force) as more false, imagined, impossible, improbable, impossible, rare (even "Reality", "Life", "Past"), while women estimated them as more real, true, inevitable, typical, existent and possible.

At the same time Canadian and Chinese men favored "Force", "Complexity", Chaos" and three timing-related concepts ("Time", "Motion", "Speed"). More specifically, men estimated them as more sharp, exciting, stimulating, interesting, pleasant, understandable, clear, regular, steady, while women estimated them as more smooth, indifferent, draining, uninteresting, irritating, inexplicable, blurred, irregular, and faltering. Canadian and Chinese men also saw Time, Motion, Speed as more ordered, reliable, planned, and rational than women. In the Russian sample the concept "Force" differed from others by having a noticeably smaller number of statistically significant sex differences. Chinese and Russian (nihilistic otherwise) men also estimated "Complexity" and "Chaos" as something more soft, warm, useful while women in these samples saw them as more rigid, cold, and harmful. Overall on the scales of the Complexity factor men had a consistent tendency to see phenomena as something more simple, easy, understandable, ordered, uniform, one-dimensional (even "Complexity", "Chaos" and their favorite object "Force") while women estimated them as more complex, difficult, inexplicable, chaotic, diverse and multi-dimensional. The only exception was the concept "Order": for Russian men "Order' was more complex than for women; Russian men also saw most of the objects as less organized than women. On the scales of the Power factor there was a tendency for men to estimate phenomena as weaker than women (i.e. more delicate, small, weak), except their favorite concept "Force" and three timing-related concepts.

4. Discussion

Overall, we found a concept-bias (i.e. men and women favored different groups of concepts) and a scale-bias (men and women used opposite poles of the scales in a consistent manner across different concepts), which were consistent in the following three aspects of meaning attribution:

(1) *Simplification* of natural phenomena: men saw them as more simple (even Chaos and Complexity) than women.
(2) *Stabilization* of natural phenomena in men, estimating them as more fixed, stable and limited, and the gravitation of women to "fluid" descriptors. This is consistent with the reported superiority of men in the ability to grasp the structural composition of objects, in the perception of shapes, and the spatial visualization of geometric and physical problems (Voyer, Voyer, & Bryden, 1995)
(3) *De-Realization of phenomena* a tendency of men to see them as more imaginary and impossible (including Reality and Life) than women while women saw

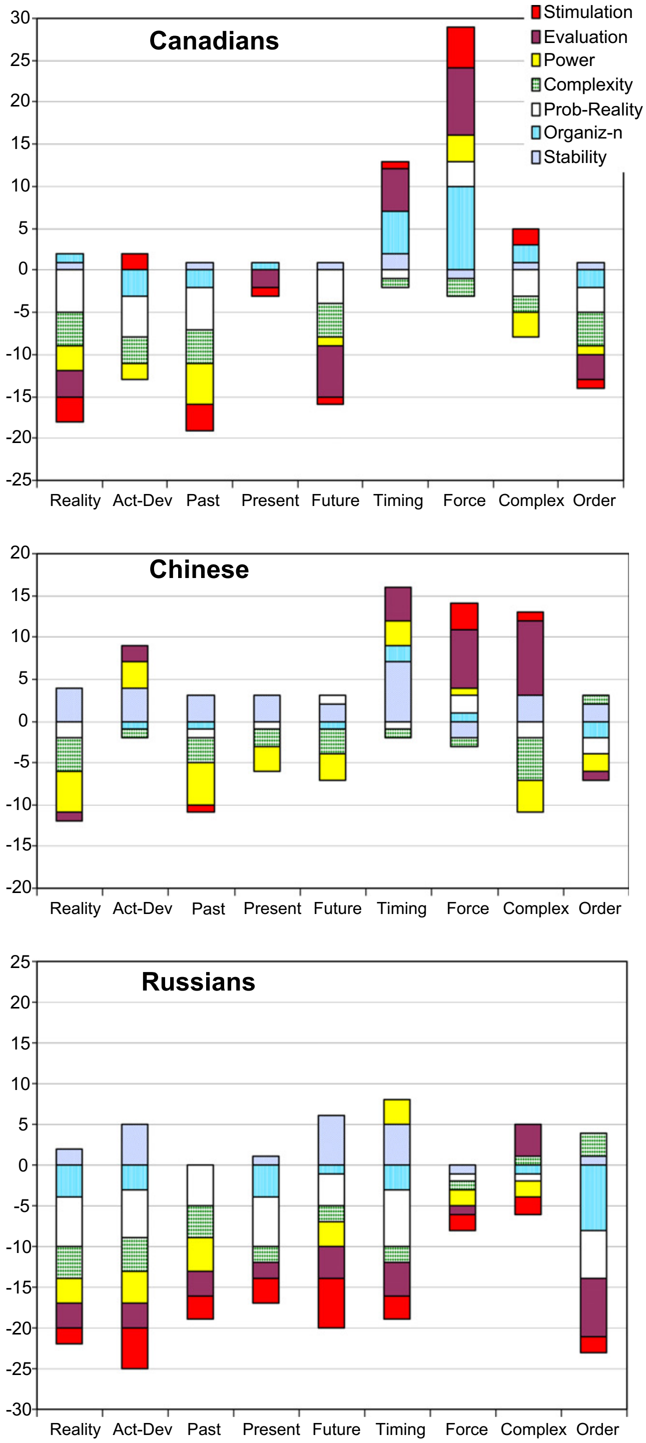

Fig. 1. The number of statistically significant (at least at $p < 0.05$) sex differences in estimations assessed with the Mann–Whitney U test. The stacked columns represent the total number of differences in the following groups of concepts: "Reality" ("Reality", "Life"), "Activity" ("Activity", "Development"), "Timing" ("Time", "Speed", "Motion"), "Order" ("Order", "Simplicity"), "Complexity" ("Complexity", "Chaos") and stand-long concepts "Past", "Present", "Future", "Force". The colors represent seven factors to which the scales are associated. The sign indicates the pole of the scales chosen by men for the given concepts (for example, a positive pole of the scales of Complexity factor is "complex" and negative pole is "simple"). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

all presented constructs as more real and possible than men, which is in line with higher rates of delusional disorders in men than in women. This is consistent with a study of 14–15 year old teens, which showed that boys' preferences in science related to subjects removed from common experience (such as weightlessness in space, or black holes), and to the mechanics of biological, chemical and nuclear weapons, while girls' preferences were related to more pragmatic and transient issues (such as the nature of illness and methods of treatment) (Jenkins & Nelson, 2005).

The combination of these three aspects in meaning attribution suggests that men are more prone to approximate natural phenomena by structures in their perception than women. Such *reduction-to-structures* appears to be a predominant approach in science, promoting mechanical, rather than evolutionary type language in science. For example, most natural sciences present their objects using the "*Lego*" *approach*, i.e. as composed of smaller constant parts. This leads to the hidden assumption that the nature of these objects could be understood from a knowledge of "what kind of bricks this stuff is made of". Analysis then focuses on the interaction between the components, but mostly in mechanical terms: "what push/pulls what in what direction using what force" leads to the measurable appearance of phenomena. Such bricks-oriented consideration is common in classical mechanics (which is the basis for engineering) dealing with interactions between theoretically stable objects; statistical mechanics considers mostly ensembles of equal elements, which also do not change in time (even when the units are chosen to be diverse they still do not change in time; in electromagnetism the processes are described in terms of interactions between quantities of internally stable units (charges).

This "Lego" approach also appears in the language of the "mother of sciences", i.e. classical mathematics, which is based on logic, placing strong boundaries on its elements and numbers ($A \neq B$). These logical assumptions lie at the basis of the majority of number systems and all methods of calculation, which are used in both discrete and continuous mathematics. Natural phenomena do not have clear boundaries due to their interactions and interdependencies, more suitably described using fuzzy logic. Fuzzy logic and process-oriented mathematics, however, are not taught in school and in undergraduate courses, except in specialized mathematics programs. Meanwhile aptitude tests used for sorting out people's fitness to do science, as well as the statistical language of reports in scientific journals, use classical mathematics and logic.

Reduction-to-structure type of analysis appears also as a predominance of geometric and topological presentations of natural phenomena in science and to an obsession with shapes, forms, morphology and other structure-oriented analysis. The evolution of natural systems is often described in terms of topological transformations, rather than factors causing the emergence of new properties or the disappearance of existing ones. Meanwhile natural objects break their topological equivalence several times during their lifetime. In spite of their deficiencies, knowledge of geometry/topology-oriented approaches and ability for topological reasoning are key requirements in mathematics and physics education, and this gives an advantage to men who apparently have a better ability to visualize problems in space.

When it comes to the description of the dynamics of some objects, the most common way is to apply a stable metric to this dynamic, i.e. to cut it into a predetermined number (or matrix) of fixed possible states (whether in physical space or a space of other variables) and then to map its travel along trajectories in this state space using a time parameter in which time intervals appear equal like in a ruler. Thus, the time ruler is fixed, and the nature or number of possible states of the system are also fixed and predetermined. Meanwhile none of the objects and phenomena in the Universe stay forever the same or live forever – at some point they emerge, develop, transform and die, and therefore the set of possible states of natural objects constantly changes: states emerge and disappear with the evolution of these objects (Trofimova, 2003). It means a changing space of parameters. Moreover, making time equivalent to a clock is a convenient simplification for engineering purposes, but it likely does not correspond to the nature of real time phenomena (Barbour, 1999).

The findings in our study showed that men in two different cultures favored the concepts "Force", "Time", "Speed", "Motion", which are the most frequently used words in classical mechanics, more than women. Such bias in using culture-free abstractions, as well as men's prevalence in physics and engineering, suggest that there might be an impact of sex on the development of early scientific language and methodology. For example, it is no secret that psychology has tried to copy methods of measurement from physics and mathematics since it's birth at the end of the 19th century, even while many formalisms of measurement theory are not applicable to this science (Guastello, Koopmans, & Pincus, 2009; Trofimova, 2000). The mechanical analysis of natural phenomena as a chain of push/pull interactions between Lego-like components might tell us "how" the components of these objects interact, but would not tell us much about the causes and emergence of new states, properties, and systemic tendencies, "why it goes this way?", and "what's next?" Answers to the latter questions relate to the transient nature of phenomena, which is difficult to visualize or to present in a Lego-built manner. These answers require process- and development-oriented languages, considering evolutionary, systemic, causal and feedback tendencies, which lead to the emergence of structures at several levels of organization; interaction between these levels (i.e. not just bottom-up phenomena), impact of the distribution of elements and their relational dynamics, causes of functional differentiation between elements, and the ability of stochastically behaving elements for self-management (Sulis, 2001; Trofimova, 2003). The emergence of new states or even properties of existing components can not be explained by the nature of these components without looking at what the system as a whole is doing or without taking into account the properties of "neighbor" systems. Due to the different time scales for their internal development, the transience of physical phenomena is less visible than changes in biological and social phenomena. Life and social sciences are full of developmental models, while developmental considerations are absent in classical mechanics, statistical mechanics, quantum mechanics, electrodynamics and any other mechanics, which use theoretically constant units changing only under the impact of certain external forces.

There are benefits to structure-oriented presentations, approximations of constancy and other mechanical approaches in science for engineering applications, but it would be sad if our science would sell itself to industries by following their mechanical languages. There are, however, social, economic, psychological and political issues of no less importance for human lives and humanity than technical progress, but sciences which deal with more transient matters are grossly underrepresented in leading journals. Our review of the topics of Perspectives, Research articles, Reports and Brevia published in the journal *Science* in 2008 showed what this journal considers "actual science" and what is just a "work in progress" (Fig. 2). Most of these publications reported findings in natural sciences (96%), giving only 4% space to social and economic sciences, which combined received much less space than genetics alone (10%). In this the Lego approach dominates: thus, microbiology articles report what biological and chemical agents interact in what structures of bodies, including gene composition; chemistry is focused on the structure of molecules and their interactions; high energy physicists are focused on elementary particles and their interactions; geology and climate science describe physical displacements of natural masses. Our results suggest that

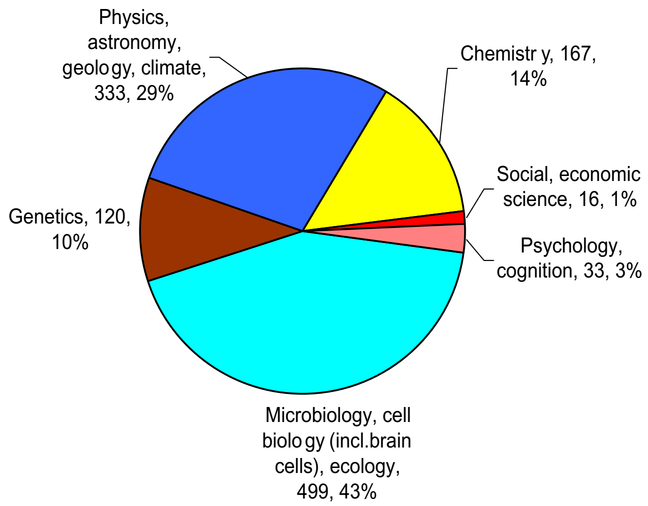

Fig. 2. Subjects of 2008 articles in Science, including Brevia, Perspectives, Reports, Research articles and some Letters.

such orientation on composition-interaction, structures-oriented analysis is more convenient for mechanically oriented men and industries, but leaves aside a fluid and multidimensional perception of phenomena, which is more natural for women. This suggests that the unequal representation of women in science in comparison to men is the result of the "mechanics"-oriented language of science. Perhaps we need to give women more chances to offer a new, process- and complexity-oriented science and mathematics? Forcing women to use the traditional language of stable metrics, to compete with men in going through predominantly geometry- and structure-oriented science, which approximate real-life phenomena too far from realism, reduces their chances for success in the development of a completely new scientific language. If science will continue with such an orientation, we soon will need to switch from Ph.D.-s to Lego.D.-s degrees.

5. Conclusion

The apparent issue of sex imbalance in natural and engineering sciences led to a recent tendency to artificially increase the number of women in these sciences. The issue however might lie in the language and methods of these sciences, which historically were developed by men and were affected by a "male type" of analysis. We found a disposition of men for simplification, reduction to structures and de-realization in the perception of natural phenomena, and a disposition of women to perceive phenomena as more complex, fluid and real. Men in all three samples also had more negative perceptions of phenomena of a transient nature, which are difficult to present in a structural way. None of our subjects had special education in physics or mathematics except high school training; the concept-related and scale-related biases in estimations of very general concepts are unlikely to be explained by any social, educational or personal factors and therefore are likely biologically based sex differences in meaning attribution. These sex differences in "mechanical vs. developing" perception raise important concerns about a hidden bias in the language of the natural sciences.

Acknowledgements

The author would like to acknowledge the hard work of our students in administration of the tests and of the Semantic Task: Kristine Espiritu, Chandrima Bandyopadhyay, Samira Patel, Vanita Marques, Iris Wen Wen, Doreen Wing Han Au, Ambreen Tahir, Azfar Ahmad Tahir, and Jennifer Bossio.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.cogsys.2011.07.001.

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