Inertia in Cognitive Process: Pigs in Space Redux[1]

Robert McIntosh

Joseph Woelfel

University at Buffalo
State University of New York

Emmanuel Lawal Jr., Carl Lam, Kristen Cassidy, Zach Arth, Samuel Hakim, Erik Messerschmidt, Yuan Tian, Yue Yang, Hong Zhu, Yumeng Shen, Scott Murszewski, Alexandra Plante

University at Buffalo
State University of New York

February, 2017

[1] We are grateful to Frank Tutzauer and Christine Iacobucci for their comments on an earlier draft of the manuscript.

The Problem

The concept of "social science" has always been problematic. As late as the mid 20th Century, when the foundations of social science methodology were being formed, even leading physicists struggling with the oddness of quantum phenomena still believed that the human mind was an immaterial phenomenon that could not interact with matter in any way (Schrödinger, 2002). Even within the social science disciplines many assert that human cultural and cognitive processes are too "volatile and evanescent" to be studied by quantitative scientific methods. In fact, most social science theory and method is based on the philosophical assumption that human beings are exceptional creatures to which normal scientific procedures, particularly measurement, do not apply in a straightforward manner.

While physical scientists and engineers define measurement, for example, as "comparison to some standard," social scientists have a totally different definition: "assignment of numbers to observations according to some rule." Ratio scaling (as social scientists call comparison to some standard) is generally assumed, mainly on philosophical grounds, to be inapplicable to the study of human cognitive and cultural processes, and a plethora of "rules" for assigning numbers to observations abound, virtually none of which would be considered measurement in the physical sciences. Some have argued that social scientists and physical scientists are actually members of separate and incompatible cultures (Tal, 2015; Snow 1998, Woelfel, 2016) and at least one highly prominent physicist denied the social sciences are science at all. Richard Feynman said "Because of the success of science, there is a kind of pseudo-science. Social science is an example of a science which is not a science." (Feynman, 2012)

Clearly, inertial factors such as distance, force, mass, and other physical concepts can not apply in an immaterial domain which does not interact with matter in any way, and where measurements are numbered categories, summated indices, checklists or simple rank orders. Yet many analysts use such concepts routinely in everyday life: political candidates, for example, have positions, they can move to the left or the right, go up or down in the polls, and they can even build or lose momentum. Are these references merely metaphorical, or do cognitive and cultural processes exhibit measurable inertial properties?

Theory

Unlike the mind, which, like all other concepts is a human construction and may — or may not — turn out to be useful for understanding human thought and action, the brain is a material object and, like all other physical objects, subject to the laws of physics. Once believed to be "…the most complex structure in the universe…", considerable progress has been made in understanding its basic mode of operation. We know that sensory inputs activate cells called neurons, and that these cells communicate with each other by means of electro-chemical processes through synapses connecting the axons and dendrites of the cells.

When a set of neurons is simultaneously active, they tend to grow new or strengthen already existing connections among themselves. Unused connections tend to wither away. The former process we call learning, and the latter forgetting. Recurring external stimuli will activate the same pattern of neurons repeatedly, and lead to strong connections among those neurons. The set of interconnections among those neurons represents the memory of that recurrent external pattern of stimuli. We will refer to these interconnected sets of neurons as *concepts* in this paper. While this account is greatly oversimplified, it illustrates the fact that the formation and change of concepts is a physical process, and not immaterial. It is reasonable, therefore, to assume that beliefs and attitudes built up over a long time and exhibiting considerable tissue mass and many interconnections would be more difficult to change than physically smaller, less "massive" clusters of inter-neural connections.

Previous Research

In 1968, A. O. Haller launched the first research project to identify the exact “significant others” for a sample of adolescent youth and to measure their expectations for their educational and occupations attainments. He and his team found that the average expectations of the set of significant others was the best predictor yet found for the youth’s own aspirations, accounting for substantially more variance than the best previous known predictors (Woelfel & Haller, 1971). Among the most important theoretical implications of this finding was the expectation that, as the “number of messages” or amount of information used to establish the mean increased, the resistance of the aspiration to change would increase proportionally (Woelfel & Hernandez, 1971).

In 1975, in a replication and extension of Haller’s research, Saltiel and Woelfel, using a multi-stage, multi-time procedure, and the same instruments designed to detect and measure interpersonal influence, gathered data from 135 high school students over a six-month interval. They found that “… the attitude of any individual converges over time on the arithmetic mean of the attitude-pertinent information received by the individual,” and that “the stability of an attitude is dependent on the number of messages out of which that attitude was formed.” They further showed that “…the emotional state or feelings of an individual and the degree of heterogeneity of influences to which he or she was exposed are unrelated to attitude change.” (Saltiel & Woelfel, 1975). Danes, et. al, in an experimental study, similarly showed that “…beliefs based on a large amount of information are more resistant to change…” (Danes, Hunter & Woelfel, 1984).

The notion that aspirations or, more generally, beliefs and attitudes, are relatively massive entities that could be “moved” by messages led to efforts to define the “space” in which these motions occurred. While early conventional factor analytic and multidimensional scaling (MDS) algorithms were too imprecise to allow measurement of the expected processes, sufficient precision could be obtained by projecting ratio scaled complete paired comparison measures onto their principle axes (Van de Geer, 1971; Jacobi, 1846; Young & Householder, 1938; Torgerson, 1958; Wisan, 1972; Gillham & Woelfel 1977; Woelfel et al 1980; Woelfel, 2009). While the common wisdom held that precise measurement of human cognitive and cultural processes was either impossible, unnecessary, undesirable or all three, research showed on the contrary that precise and reliable spaces could be established using these procedures (DeLeo, 1976; Gordon, 1976; Gordon & DeLeo, 1976; Barnett & Woelfel, 1979, 1982) and that predictable, measurable movements of cognitive objects could be produced within those spaces (Cody, Marlier & Woelfel, 1975; Barnet, Serota & Taylor, 1976; Woelfel, Meadows & Wallace, 1978; Cody, 1980; Lim, 2008).

Since then, several studies have shown behavior within the space that is consistent with elementary mechanics, and which provide credible evidence that cognitive and cultural processes may indeed be modeled as inertial systems (Kincaid, Yum, Woelfel & Barnett, 1983; Maase, Fink & Kaplowitz, 1984; Foldy & Woelfel, 1990; Fink, Kaplowitz & Hubbard, 2002; Dinauer, 2003; Dinauer & Fink, 2005; Chung & Fink, 2008; Chung, Fink & Kaplowitz, 2008).

The first direct attempt to measure the inertial masses of cognitive objects was made by Barnett (Barnett, 1988). His study was part of a continuing program of research called The Galileo System, which rejects conventional social science methodology in favor of a model that defines cognitive processes as movements of concepts through a multidimensional non-Euclidean space. Measuring the distances among these concepts emulates physical science measurement practice by measuring the inter-point distances as ratios to an arbitrary standard distance. The resulting matrix of inter-point distances is projected onto a multi-dimensional non-Euclidean spatial coordinate system (Woelfel & Fink, 1980). Cognitive and cultural processes are defined within this system as motions in the space (Woelfel & Stoyanoff, 2007).

Barnett hypothesized that words that occurred more frequently in English would likely be encountered more often than those occurring less often, and therefore would exhibit higher inertial mass, which he could measure as the inverse of the distances they moved through the Galileo space when they were manipulated. He chose for study four synonyms, pig, hog, boar and swine, all of which refer to the same animal, but which occur with differing frequency in English.

Barnett tried to influence subjects' beliefs and attitudes about each of the four synonyms by allowing them to read a statement that said, "Did you know, for example, that [pigs, hogs, boar, swine] are beneficial and attractive?" In four matched control groups, the sentence was omitted. He then had subjects estimate the differences or "distances" among all pairs of these concepts and eleven additional concepts (cow, dog, cat, goat, horse, sheep, good, bad, beneficial, attractive and myself, as ratios to the comparative standard dogs and cats are 50 units apart. The averages of these paired comparison estimates were then projected onto their principle axes to generate a reference space against which the motions of the experimental concepts could be assessed. He anticipated that the synonyms that occurred most frequently in English would move the least in the reference space.

Three of the manipulated concepts —pig, hog and swine — behaved as Barnett expected, but the fourth, boar, did not:

> Again, if boar is removed from the analysis, the results are as predicted. The

correlations of the differences with the frequency of occurrence as reported by Thorndike and Lorge was 1.0 and the correlation of these differences with the use estimates was r = .94, F = 7.36.36 (Barnett 1988)

The goal of the present research is to replicate Barnett's original study with some enhancements due to research during the intervening 37 years. Replicating Barnett's findings after nearly four decades would go a long way toward disproving the notion that human attitudes and beliefs are too "volatile and evanescent" to be studied scientifically using the same measurement principle (comparison to some standard) that serves as the foundation of measurement in the physical sciences.

Methods

Barnett's sample consisted of 241 undergraduates at an Eastern US urban engineering institute.

He instructed all of his respondents as follows:

U.S Department of Agriculture 216 N. "E" Street
Washington, D.C. 20002
TO BE RELEASED: On or before March 15, 1979
FOR FURTHER
INFORMATION
CONTACT: Douglas Ranier

Gene Shallit may not recommend this book for its literary merits but it will be the most important volume to be published this year," said Dr. Margaret Staltman. Staltman is director of a task force appointed by the U.S. Department of Agriculture to compile the latest data on animal husbandry and livestock management. This volume will be invaluable to farmers with an investment in livestock. "This volume on livestock management will be full of interesting and practical facts, figures and forecasts."

"For example," said Dr. Staltman, "did you know that pigs are beneficial and attractive?"

The volume will be entitled, A Modern Guide to Animal Husbandry and Livestock Management, and will be published in June 1979.

Barnett’s instructions represent early beliefs among researchers in the field of Communication that attitude change was hard to achieve, and that plausible persuasive messages delivered by credible sources were necessary to assure measureable effects. Subsequent research has shown that the ratio-scaled paired comparisons are precise enough to detect even the subtlest of wording, and that such elaborate messages are neither necessary nor desirable, but rather generate significant noise into the system (Woelfel, 2016; Craig, 1977)

In four control conditions, one for each of Barnett’s treatment conditions, the line beginning “For example,” was excluded. In each of four treatment conditions, the line was included, substituting one of the four synonyms, i.e., pigs, hogs, boar or swine.

All respondents were then asked to estimate how different or “far apart” each of twelve (Barnett included only one synonym in each condition) concepts were from each other, which required (12X11)/2 = 66 paired comparisons. These concepts were bad, myself, cow, beneficial, dog, cat, horse, good, sheep, attract, goat, pig, hog, boar and swine. To provide a comparative standard, respondents were told that the distance between dogs and cats was 50 units, that zero (0) meant no difference at all, and that they could choose numbers larger or smaller than 50 if they so choose.

The 241 complete questionnaires were entered into the Galileo Version 5.2 computer program (Woelfel & Fink, 1980), which averaged all responses across respondents after deleting extreme values 3 standard deviations or greater than the largest mean distance plus the mean, calculated the spatial coordinates of the four control groups and four treatment conditions and rotated and translated the treatment spaces onto the control spaces, minimizing the squared control-treatment distances among untreated (stable) concepts. This resulted in a stable reference system against which motions of the treated (free) concepts could be gauged (Woelfel, Holmes

& Kincaid, 1980; Woelfel & Barnett 1989; Hsieh, 2004). The relative inertial masses of the treated concepts could then be estimate as the inverse of the distances moved relative to the fixed concepts within the space.

In our replication, 571 respondents participated in an experiment conducted during fall 2015-spring 2016 academic year at a large, urban public university in the Northeastern U.S. Our sample differed from Barnett's in two important ways: his students were primarily male engineering students to whom mathematics would be familiar and comfortable, while our sample was about half male and female social science students for whom mathematics would be uncomfortable.

Respondents were randomly assigned to one of five conditions; a control condition and four treatment conditions. All completed identical Galileo-type ratio scaled complete paired comparisons questionnaires including the fifteen concepts from Barnett's original study, although in a different order. All questionnaires used the standard Galileo instructions printed by the questionnaire generating software, AQM:

> This questionnaire will ask you for your opinion about several animals.
> Did you know, for example, that pigs are beneficial and attractive?
>
> Instructions
> Please estimate how different or "far apart" each of the following words or phrases is from each of the others. The more different, or further apart they seem to be, the larger the number you should write. To help you know what size number to write, remember
>
> cat and dog are 50 units apart
>
> If two words or phrases are not different at all, please write zero (0). If you have no idea, just leave the space blank.
> Thank you very much for your help.

```
               ----------------------------------------------------------
                cat and dog are 50 units apart
       COL.    ----------------------------------------------------------
0102   9-17    cow                        and  dog                  _____
0103  18-26    cow                        and  horse                _____
0104  27-35    cow                        and  cat                  _____
0105  36-44    cow                        and  beneficial           _____
0106  45-53    cow                        and  sheep                _____
0107  54-62    cow                        and  good                 _____
0108  63-71    cow                        and  goat                 _____
0109  72-80    cow                        and  attractive           _____
               ----------------------------------------------------------
```

The questionnaire then presented the resulting (15X14)/2 = 105 comparisons in blocks of eight:

In the control condition, the sentence “Did you know, for example, that pigs are beneficial and attractive?” was omitted. In each of the four treatment conditions, the appropriate synonym for pig was included in the sentence.

Results

Barnett’s design did not include all four synonyms in any single questionnaire, but his study and ours shared 11 concepts, giving (11X10)/2= 55 pair comparisons in common. Barnett filtered his extreme values greater than 3 standard deviations plus the mean of his largest mean distance, which was “bad” - “good”. Using the same algorithm on our own data yielded a maximum value filter of 4207; all values higher than this were deleted from the data. (4207 is over 84 times larger than the nominal distance between the comparative standard dog and cat, which is 50.)

Comparing the 55 mean values common to both studies gave a correlation of r=.877, p<.0001, DF=53, t=13.2. Entering both sets of means into the Galileo version 5.7 program yielded spaces with very similar structures, as shown by the plots of the first three dimensions in

Figure 1.

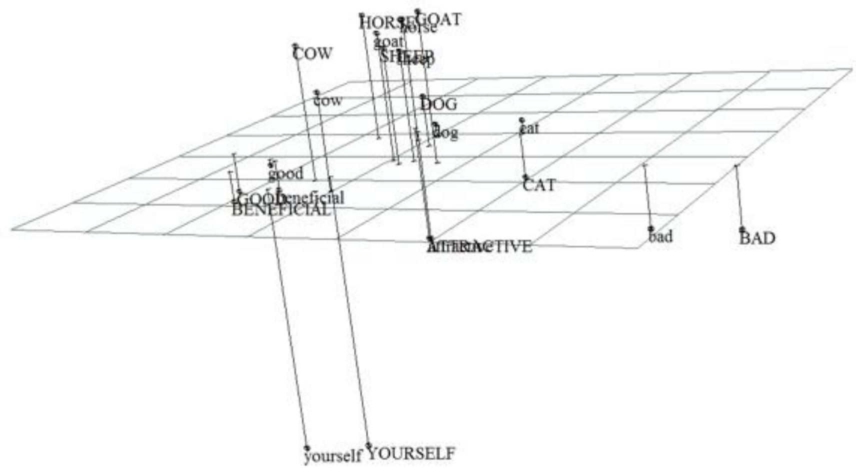


Figure 1: Barnett's Data (Upper Case) and Replication after 37 Years (Lower Case)

Both spaces are reliably multidimensional and non-Euclidean, with each producing 7 real dimensions and 3 imaginary dimensions, although the smallest of the imaginary dimensions is only about 20% of the nominal distance between cat and dog in length.

Because the space is multidimensional and non-Euclidean, the distances among elements in the spaces are calculated by the extended theorem of Pythagoras:

$$s_{ab} = \sqrt{\sum_{\mu=1}^{N} \left(x_{\mu a} - x_{\mu b}\right)^{2}}$$

Equation 1: Extended Theorem of Pythagoras

Where:
s_{ab}= the distance between concept a and concept b
$x_{\mu a}$= the coordinate of concept a on the μth dimension
$x_{\mu b}$= the coordinate of concept b on the μth dimension
N = the number of dimensions

Since some of the dimensions of the space are imaginary, their squares are negative; these are therefore subtracted from the sum in Equation (1). The mean distance between corresponding concepts in Barnett's space and our space was 18.70 units, which is about 37% of the nominal distance between dog and cat. Correlations among the dimensions and the position vectors of the concepts across the 37-year interval are presented in Table 1:

Table 1: Relationships Between the Spatial Reference Frames Across 37 Years

Correlations among the position vectors

Concept	T1 Magnitude	T2 Magnitude	Correlation	Angle
1 Bad	93.34	71.51	0.988649	8.6
2 Self	69.90	75.03	0.960027	16.3
3 Cow	47.06	42.20	0.914279	23.9
4 Beneficial	38.32	29.10	0.767806	39.8
5 Dog	39.29	38.73	0.789872	37.8
6 Horse	49.08	52.71	0.948125	18.5
7 Cat	51.29	53.91	0.922482	22.7
8 Good	42.69	25.12	0.667405	48.1
9 Sheep	41.66	42.01	0.987697	9.0
10 Attractive	40.48	37.66	0.996701	4.7
11 Goat	49.60	46.79	0.963079	15.0

Correlations among the dimensions

Dimension	T 1 Magnitude	T 2 Magnitude	Correlation	Angle
1	127.62	98.00	0.972411	13.5
2	113.81	103.41	0.980088	11.5
3	59.42	69.49	0.939563	20.0
4	52.56	45.21	0.856567	31.1
5	42.81	62.83	0.922666	22.7
6	34.44	42.23	0.702645	45.4
7	26.09	34.17	0.857776	30.9
8	0.19	0.26	0.873177	29.2
9	10.62	8.85	0.505827	59.6
10	40.60	40.42	0.916274	23.6
11	77.15	76.15	0.954882	17.3

Given the demographic differences between the two samples and the 37 year intervening period, the degree of similarity of the original space and our replication is clear evidence that this particular cognitive structure is not "volatile and evanescent", and the comparative measurement procedure is capable of excellent precision and stability.

Calculating the Masses

Data from all four experimental groups and the control group were read into the Galileo v5.7 computer program, which calculated the eigenvectors and eigenvalues of all five reference frames. Each treatment group was then compared to the control group by rotating it to least squares best fit on the control space. Since some of the objects (i.e., the synonyms and the words beneficial and attractive) were manipulated in the experiment, they could not be expected to remain stable, and were excluded from the least squares minimization: in each condition, the treatment and control condition were translated to common origin of the non-manipulated concepts and rotated until the squared distances among the non-manipulated concepts was a minimum. The distances between the location of the treated concepts in the control frame and the experimental frame could then be calculated and are presented in Table 2:

Table 2: Distances Moved by Condition; Maxval=4207; Fcons=5,9,11,12,13,14

		Pig	hog	boar	swine	Totals
pig		16.5	81.8	89	88.6	275.9
hog		29.7	60.3	74.4	61.9	226.3
boar		18.7	72.8	99.2	110.9	301.6
swine		19.5	94.5	75.8	126.7	316.5
Totals		84.4	309.4	338.4	388.1	1120.3
p=	0.001494156					

As Barnett predicted, the less frequently occurring synonyms moved most; assuming that the force acting on each synonym is the same, we can estimate the inertial masses of the synonyms by calculating the ratios of their movements. Setting the mass of Pig at 1, they are: Pig=1.0, Hog=.26, Boar=.27, and Swine=.2.

Table 3 shows the correlations among the calculated masses and the frequency of their occurrences in English by two different indexes (Thorndike & Lorge, 1944) which Barnett used, and a more recent index, the Corpus of Contemporary American English (COCA), current as of 2000 (Davies, 2000).

Table 3: Correlations of Synonym Masses and Frequency of Occurrence; Maxval=4207

Synonym	T-L	CHAE	Mass
pig	44	531	1
hog	14	146	0.26
boar	11	168	0.27
swine	8	40	0.2
r =	0.995	0.983	

Table 4 shows that the synonyms cannot be considered independent. Moving any synonym closer to the attributes beneficial and attractive also reduces the distance between each of the other synonyms and the attributes. This is true regardless of which of the synonyms is manipulated. This is reasonable, since the synonyms refer to the same animal — that is, they are all names of the same concept — and it appears that all the synonyms move as a relatively rigid unit toward the attributes.

Table 4: Distances of Synonyms from Attributes by Condition; Maxval=4207

	control	pig	hog	boar	swine	Total
pig-bene	83	57.3	39.2	55.3	46.5	281.3
hog-bene	98.6	61.8	48.6	51.6	54.9	315.5
boar-bene	107.2	65	50.6	52.8	67	342.6
swine-ben	87	67.6	53.1	63.9	56.4	328
pig-att	96.4	84.8	91	72.5	92.4	437.1
hog-att	97.9	78.5	87.6	81.2	103.6	448.8
boar-att	124.9	85.7	95.1	82.6	75.9	464.2
swine-att	102.7	87	82	79.3	84.4	435.4
Total	797.7	587.7	547.2	539.2	581.1	3052.9
F=	1.0277E-151	DF 8, 5	NS			

Table 5 shows the distances moved of all the manipulated concepts, including the four synonyms and the two attributes beneficial and attractive in each of the experimental conditions. The total distance moved by all of the concepts in each condition correlates with the calculated masses of the manipulated concept r=-.967, which indicates that the total movement is greatest when the least massive concept is manipulated. While this may appear odd at first, the least massive concepts are also most distant from the other synonyms and also from the attributes, so manipulating them produces the greatest amount of force as estimated by amount of advocated change. We assume that forces are, at least over relatively short distances, roughly proportional to the total distance between the location of the concepts and the location to which the message suggests the concepts should be relocated. Again, estimating the total force applied as the total change advocated (see Table 6) gives a correlation between total change advocated and total change observed as r=.971

Table 5: Distance Moved by Condition; Maxval=4207; Fcons=5,9,11,12,13,14

	Pig	hog	boar	swine	Sum
pig	16.5	81.8	89	88.6	275.9
hog	29.7	60.3	74.4	61.9	226.3
boar	18.7	72.8	99.2	110.9	301.6
swine	19.5	94.5	75.8	126.7	316.5
beneficial	50	40.1	27.9	53.3	171.3
attractive	60.8	52.3	53.2	58.5	224.8
yourself*	33.1	15.3	10.6	15.5	74.5
Sum	195.2	401.8	419.5	499.9	1516.4

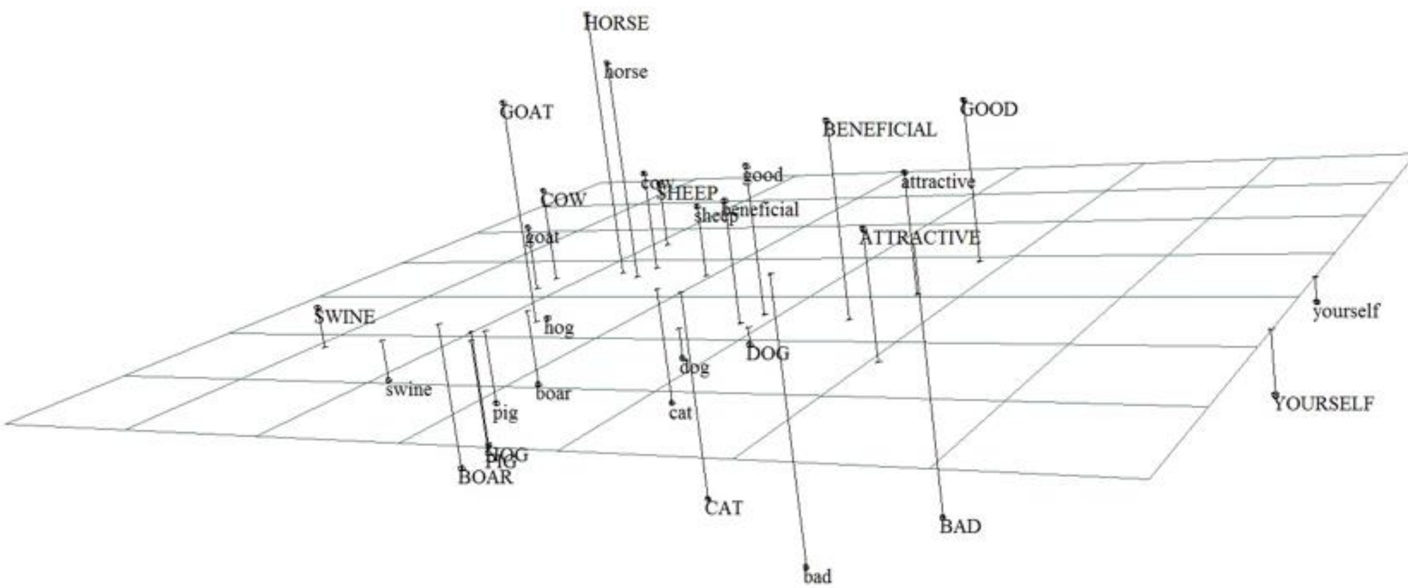
*not included in sum Mean=101.1

Total Motion	Force
195.2	299.8
401.8	380.2
419.5	400.3
499.9	401.9
r=.971	

Table 6: Correlation of Total Motion with Total Force (Change Advocated)

Figure 2 shows the movements of the manipulated concepts in the first three dimensions of the multidimensional space for the Pig condition:

Figure 2: Pig Condition. Uppercase=Control; Lowercase= Treatment.



Pig is the most massive concept by a good margin, and also the concept with the least force as measured by amount of change advocated (195.2 units, or 3.9 times the distance between dog and cat). Accordingly, while all the manipulated concepts show movements toward one another, the movements are quite small.

Figure 3 shows movements in the Hog condition. Since this is a lower mass condition with higher change advocated (401.8 units, or about 6.7 times the difference between dog and cat), the movements are considerably more sizable than those in the Pig condition. Assuming that the total mass of the system of all four synonyms remains the same, it is possible to estimate the relative forces applied in each of the experimental conditions as the inverse ratio of the movements of the total system including all synonyms and the attributes.

Figure 3: Hog Condition. Uppercase= Control; Lowercase= Treatment.

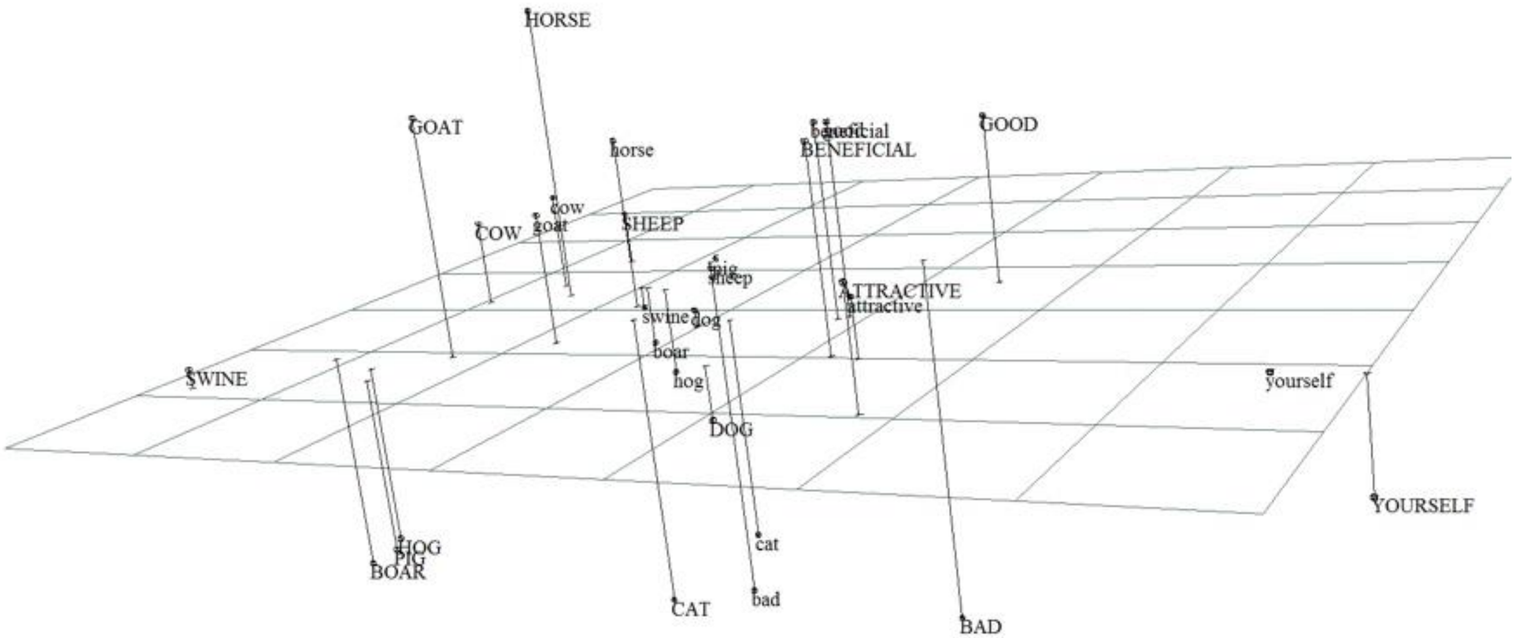


Figure 4 shows the movements in the Boar condition with 419.5 units of change advocated, or about 8.4 times the distance between dog and cat), which also show considerable motion of the manipulated concepts.

Figure 4: Boar Condition. Uppercase= Control; Lowercase= Treatment.

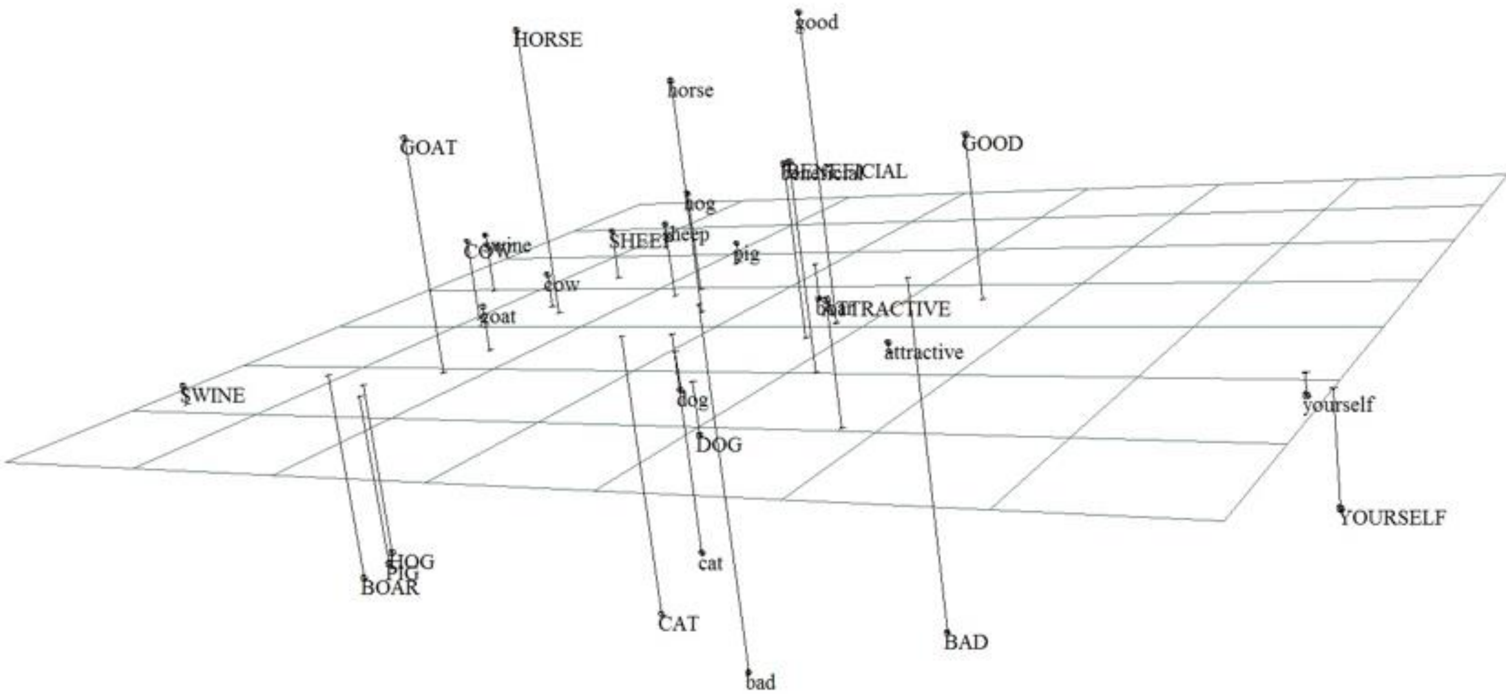


Figure 5 shows the Swine condition, which has the lowest mass, highest force measured by total change advocated (499.9 units, or about 10 times the distance between dog and cat), and also the greatest motion.

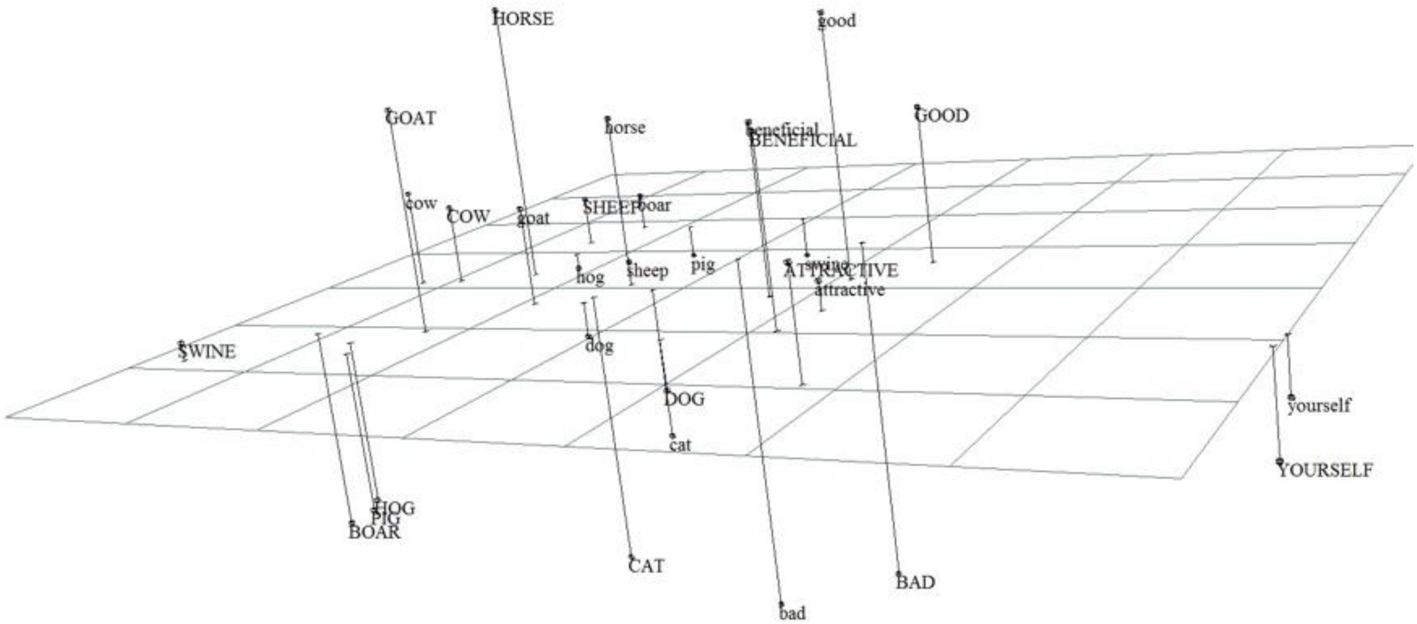


Figure 5: Swine condition. Uppercase= Control; Lowercase= Treatment.

A possible interpretation of these data is that the space in which these objects are embedded is warped by the treatment messages. Some evidence in favor of this interpretation is given by the behavior of the warp factor. When a space is fully Euclidean, it's eigenvectors are all real, but imaginary eigenvectors mean the space is non-Euclidean. The sum of squares of the coordinates on any dimension is called the eigenvalue associated with that eigenvector, and represents the squared length of that dimension. When the coordinates are imaginary, their squares and the resulting sum of squares or eigenvalue is negative (Woelfel & Barnett, 1982).

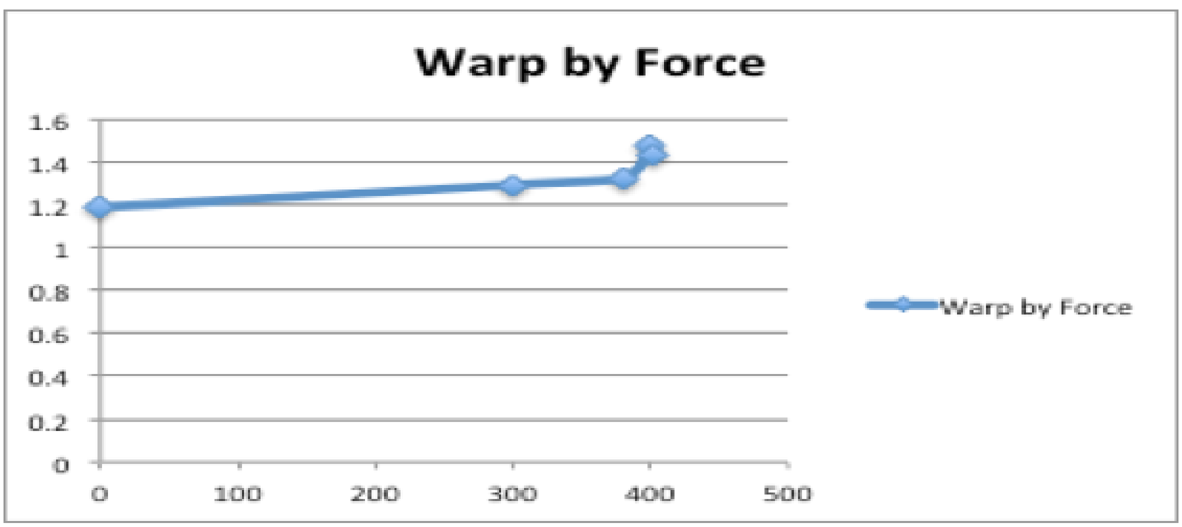
The sum of all the eigenvalues associated with real dimensions divided by the sum of all the eigenvalues is called the warp factor (Woelfel & Fink, 1980) If there are no imaginary dimensions, the sum of all the eigenvalues is equal to the sum of the positive eigenvalues, and the warp factor is 1.0. If there are any imaginary eigenvectors, their eigenvalues are negative, so the sum of all eigenvalues is smaller than the sum of the positive eigenvalues, which yields a warp factor great than 1.0.

Table 7 shows the correlation between the Warp Factor and Force for each condition. Figure 6 and Table 7 show that the warp factor increases in the treatment conditions, and that the increase is highly correlated with the total force measured as total change advocated. Figure 6 shows that this increase is almost linear at first, with a quick upturn at the highest values:

Table 7: Warp by Force
r=.869

	Warp	Force
Control	1.1821	0
Pig	1.2912	299.8
Hog	1.3249	380.2
Boar	1.4747	400.3
Swine	1.4311	401.9

Figure 6: Warp by Force



Discussion

The results of this research have important implications for the study of cultural and cognitive processes. The good fit of our data to Barnett's 37-year-old results indicates that measurement by comparison to an arbitrary standard (ratio scaling) can provide precise and reliable data, and that the structure of the cognitive domain of barnyard animals remains quite stable over the 37-year period.

Substantively, the results are supportive of Barnett's original speculation that the inertial masses of cognitive objects are proportional to their frequency of occurrence. This is consistent with the underlying model of concepts as more or less massive clusters of neural tissue whose mass is itself a function of their information history, and whose resistance to change is a function of their physical mass.

The results are also supportive of the general theoretical framework utilized by these two studies: cognitive and cultural processes may be represented as motions among points embedded in a multidimensional non-Euclidean spatial reference system in which the differences among the objects perceived by respondents are represented as distances in the space. These distances can be measured by asking respondents to report their distances or differences as ratios to an arbitrary standard distance in the space.

Forces can be imposed on the objects in the space in the form of "messages" of the form [A,B..N] = [a,b…n]; e.g., "cows and horses are useful, attractive and expensive", or "social science is pseudo science." Forces are, at least over relatively short distances, roughly proportional to the total distance between the location of the concepts and the location to which the message suggests the concepts should be relocated. Finally, objects move (or the space is warped) proportionally to the forces, and inversely proportionally to their inertial masses.

The fact that the objects in the domain can be moved easily by simple messages, yet the domain remains stable over 37 years, implies that some equilibrium processes are at work. These might be modeled as restoring forces within the system, or by sociological factors in which external messages restore the domain to its original state, or by some combination thereof.

While the random assignment posttest only design of the current experiment is too limited to establish exact functional relations, even in its crude form the model fits experiment to much closer tolerances than conventional social science theory and method. How well does it hold up against the best of traditional social science results? Perhaps the most widely accepted theory of cognitive processes in the social science literature is the Theory of Reasoned Action and its alternative, the Theory of Planned Behavior:

> "Based on the data presented in Table 1, a frequency-weighted average correlation for the I-B relation- ship was 0.53. This correlation is based on 87 separate studies with a total sample of 11,566 and is significant at the 0.01 level. Based on the data presented in Table 2, a frequency-weighted average correlation for the A+SN-I relationship was 0.66. This correlation is based on 87 separate studies with a total sample of 12,624 and is significant at the 0.001 level. These results provide strong support for the overall predictive utility of the Fishbein and Ajzen model" (Sheppard & Warsaw, 1988).

Meta-analysis of research on the Theory of Planned Behavior shows that this theory does no better, as Armitage and Connor point out:

> The Theory of Planned Behaviour (TPB) has received considerable attention in the literature. The present study is a quantitative integration and review of that research. From a database of 185 independent studies published up to the end of 1997, the TPB accounted for 27% [r=.52 –Ed] and 39% [r=.62—Ed] of the variance in behaviour and intention, respectively...The present meta-analysis provides support for the efficacy of the TPB as a predictor of intentions and behaviour. Although prediction is superior for self-reported than observed behaviour, the TPB is still capable of explaining 20% of the variance in prospective measures of actual behaviour (i.e. a medium to large effect size). (Armitage & Conner, 2001).

This general model is clearly one of the most widely held theories in psychology, and very substantial evidence over several decades show correlations between theory and experiment between .4 and .66, which social scientists call “strong support” and refer to the explanation of 20% of the variance — an 80 % error rate — as “…a medium to large effect size.”

In contrast, the Galileo model reported here shows substantive correlations ranging from .868 to .995 between theory and experimental results. These results are several times more precise than the most widely believed indigenous psychological theories which dominate the social sciences, and warrant further research on the Galileo model. More important than the Galileo model, however, which is just a model, and these come and go, our results indicate that human cognitive and cultural processes can and should be studied with the same methods and held to the same standards as any other branch of scientific research.

References

Armitage, C. & Conner, M. Efficacy of the Theory of Planned Behaviour: a meta-analytic review. *British Journal of Psychology* **40**, 28 (2001).

Barnett, G. A. & Woelfel, J. On the dimensionality of psychological processes. *Quality and Quantity* **13**, 215-232 (1979).

Barnett, G. A. 1988. "Frequency of Occurrence as an Estimate of Inertial Mass: Pigs in Space." Pp. 243-64 in *Readings in the Galileo System: Theory, Methods, and Application* edited by G. A. Barnett and J. Woelfel. Dubuque, IA: Kendall/Hunt.

Barnett, G. A. in *Readings in the Galileo system: Theory, methods, and application* (eds G.A. Barnett & J. Woelfel) 243-264 (Kendall/Hunt, 1988).

Barnett, G. A., Serota, K. & Taylor, J. Campaign communication and attitude change: A multidimensional analysis. *Human Communication Research* **2**, 227-244 (1976).

Chung, S. & Fink, E. L. The cognitive dynamics of beliefs: The effect of information on message processing. *Human Communication Research* **34**, 477-504 (2008).

Chung, S., Fink, E. L. & Kaplowitz, S. A. The comparative statics and dynamics of beliefs: The effect of message discrepancy and source credibility. *Communication Monographs* **75**, 139-170 (2008).

Cody, M. J. in *Communication Yearbook* (ed D. Nimmo) (Transaction Books, 1980).

Cody, M., Marlier, J. & Woelfel, J. in Eighth Annual Mathematical Psychology Meeting (West Lafayette, IN, 1975, August).

Craig, R. T. Limiting the scope of the spacial model of communication effects. *Human Communication Research* **3**, 309-325 (1977).

Danes, J. E., Hunter, J. E. & Woelfel, J. in Mathematical models of attitude change: Vol. 1. Change in single attitudes and cognitive structure (eds J. E. Hunter, J. E. Danes, & S. H. Cohen) 204–216 (Academic Press, 1984).

Davies, M. (Brigham Young University, Brigham Young University, 2000).

DeLeo, H. C. A technique for the development of strategies for attitude change: Multidimensional scaling of sex-role concepts, Temple University, Philadelphia, PA., (1976).

Dinauer, L. & Fink, E. L. Interattitude structure and attitude dynamics: A comparison of the hierarchical and galileo spatial-linkage models. *Human Communication Research* **31**, 1-32

(2005).

Dinauer, L. Attitude and belief change in explicit and implicit concept hierarchies: A comparison of two models of interattitudinal structure PhD thesis, University of Maryland, (2003).

Feynman, R. P. *Social Science*, <http://www.youtube.com/watch?v=IaO69CF5mbY> (2012).

Fink, E. L., Kaplowitz, S. A. & Hubbard, S. M. in *The persuasion handbook: Theory and practice* (eds J. P. Dillard & M. Pfau) 17-37 (Sage Publications, 2002).

Foldy, J. & Woelfel, J. Conceptual structures as damped harmonic oscillators. *Quality & Quantity* **24**, 1-16 (1990).

Gillham, J. & Woelfel, J. The Galileo system of measurement: Preliminary evidence for precision, stability, and equivalence to traditional measures. *Human Communication Research* **3**, 223-234 (1977).

Gordon, T. & Deleo, H. C. in International Communication Association conference (Portland, OR, 1976, April).

Gordon, T. *Subject abilities to use MDS: Effects of varying the criterion pair* (Retrieved from Galileoco, Galileo Literature #21. (http://www.galileoco.com/CEtestLit/literature.asp), 1976).

Hsieh, R. Comparison across the reference frame: Rotation of Galileo spaces with inconsistent objects--an example of comparison of user's perceptions and online legal policies PhD thesis, University at Buffalo, (2004).

Jacobi, C. G. J. Über ein leichtes Verfahren, die in der Theorie der Säkularstörungen vorkommenden Gleichungen numerisch aufzulösen. *Crelle's Journal (in German)* **30**, 43 (1846).

Kincaid, D., Yum, J., Woelfel, J. & Barnett, G. A. The cultural convergence of Korean immigrants in Hawaii: An empirical test of a mathematical theory. *Quality and Quantity* **18**, 59-79 (1983).

Lim, Y. Persuasive Message Strategy for International Development Campaigns: A Theoretical Application of the Galileo Spatial-Linkage Model PhD thesis, University at Buffalo, State University of New York, (2008).

Maase, S. W., Fink, E. L. & Kaplowitz, S. A. in *Communication yearbook 8* (ed R. N. Bostrom) 80-105 (Sage Publications, 1984).

Saltiel, J. & Woelfel, J. Inertia in cognitive processes: The role of accumulated information in attitude change. *Human Communication Research* **1**, 333-344 (1975).

Schrödinger, E. Nature and the Greeks and Science and Humanism. (Cambridge University Press, 2002).

Sheppard, J. H. & Warshaw, P. R. The Theory of Reasoned Action: A Meta-Analysis of Past Research with Recommendations for Modifications and Future Research. *The Journal of Consumer Research* **15**, 18 (1988).

Snow, C. P. *The Two Cultures*. (Cambridge University Press, 1998).

Tal, E. in Measurement in Science, The Stanford Encyclopedia of Measurement (ed Edward N. Zalta) (2015).

Thorndike, G. & Lorge, I. The Teacher's Word Book of 30,000 Words. (Columbia University, 1944).

Torgerson, W. Theory and Method of Scaling. (Wiley, 1958).

Van de Geer, John Introduction to multivariate analysis for the social sciences. San Francisco : (W. H. Freeman, 1971)

Wisan, G. The construction of a continuous manifold for social objects: A prolegomenous study PhD thesis, University of Illinois at Urbana-Champaign, (1972).

Woelfel, J. & Barnett, G. A. Multidimensional scaling in Riemann space. *Quality and Quantity* **16**, 469-491 (1982).

Woelfel, J. & Fink, E. L. The measurement of communication processes: Galileo theory and method. (Academic Press, 1980).

Woelfel, J. & Haller, A. Significant others: The self-reflexive act and the attitude formation process. *American Sociological Review* **36**, 74-87 (1971).

Woelfel, J. & Hernandez, D. A Theory of Linear Force Aggregation (Urbana, 1972).

Woelfel, J. & Stoyanoff, N. in The Galileo System: A rational alternative to the dominant paradigm for social science research Vol. 3 Freiberger beiträge zur interkulturellen und wirtschaftskommunikation: A forum for general and intercultural business communication (ed M. Hinner) 433-462 (Peter Lang, Berlin, Germany, 2007).

Woelfel, J. Multivariate analysis as spatial representations of distances. (RAH Press, 2009).

Woelfel, J. The Culture of Science: Is Social Science Science? (Rah Press, 2016).

Woelfel, J., Barnett, G. A., Pruzek, R. & Zimmelman, R. Rotation to simple processes: The effect of alternative rotation rules on observed patterns in time-ordered measurements.

Quality & Quantity **23**, 3-20 (1989).

Woelfel, J., Cody, M. J., Gillham, J. & Holmes, R. A. Basic premises of multidimensional attitude change theory: An experimental analysis. *Human Communication Research* **6**, 153-167 (1980).

Woelfel, J., Holmes, R. & Kincaid, D. *Rotation to congruence for general Riemann surfaces under theoretical constraints* (Retrieved from Galileoco, Galileo Literature #19. (http://www.galileoco.com/CEtestLit/literature.asp), 1980).

Woelfel, J., Meadows, C. & Wallace, R. in 70th Annual Meeting of the Journal of Animal Science (East Lansing, MI, 1978).

Young, G. & Householder, A. Discussion of a set of points in terms of their mutual distances. *Psychometrika* **3**, 4 (1938).