Fire and Ice: Cultural Influences on Complex Problem Solving

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Abstract

Previous research on complex problem solving (CPS) has been conducted mostly in western-industrialized countries and has often focused on individual differences such as intelligence to explain performance. We tested a model postulating that cultural values influence CPS strategies and CPS strategies in turn influence performance when controlling for individual difference variables. Participants were 535 students in five countries: Brazil, India, Germany, the Philippines, and the United States. They had to protect cities from fires and prevent goods from perishing in two microworlds with different demands. Fit indexes show reasonable fit of the theoretical model in the two microworlds. Results highlight the influence of culture on CPS.

Keywords: Complex problem solving; Dynamic Decision Making; Culture; Values; Strategies; Performance; Horizontal and Vertical Individualism and Collectivism.

Microworlds

Imagine you are the commanding officer of a fire brigade. You have several trucks and helicopters to protect three small villages surrounded by forests. Imagine you are the manager of a supermarket responsible for a coldstore full of dairy products. Suddenly, the automatic temperature device breaks down and you have to manually control the temperature to keep products from spoiling.

We presented the fire and coldstore problems as computer simulations WINFIRE (Gerdes, Dörner, & Pfeiffer, 1993) and COLDSTORE (Reichert & Dörner, 1988) to participants from Brazil, India, Germany, the Philippines, and the United States.

The goal of this study was to test a theoretical model postulating that cultural values predict problem-solving strategies and performance in these two simulations with different demands. Such simulations are also called micro-worlds (Brehmer & Dörner, 1993) and are commonly used in the field of complex problem solving (CPS) and dynamic decision making (DDM). The advantage of microworlds is that they represent aspects of problems in real life, such as a situation's complexity and dynamic development, as well as opaqueness of some aspects, yet they offer the possibility for controlled laboratory studies (Frensch & Funke, 1995).

We chose the two simulations WINFIRE and COLDSTORE because of the different challenges they pose to the problem solver. In WINFIRE, the participant has to make quick decisions under time pressure in order to extinguish and contain fires. WINFIRE can be characterized as highly dynamic with many changes occurring, low in opaqueness as it shows on the screen most of what is happening, and medium in complexity because it consists of many interconnected variables. Von Clausewitz's (1832) two principles underlying all strategic planning, i.e., utmost concentration of sources and utmost speed, are essential in WINFIRE. An action-oriented strategy is expected to lead to success.

In order not to favor cultures that prefer making fast decisions, we also chose COLDSTORE (Dörner, 1996), which does not require the same urgency and quick response. In COLDSTORE, the participant has to monitor temperature changes to regulate or maintain an ideal of 4° Celsius (39° Fahrenheit). COLDSTORE can be described as moderately dynamic since decisions have delayed effects, high in opaqueness as the delayed effect of actions is not obvious, and low in complexity as it only consists of three variables. A cautious, less action-oriented strategy is expected to lead to success. This characterization of the microworlds was confirmed through participants' subjective ratings (Güss et al., 2004).

Culture and Complex Problem Solving

Previous research on CPS has been conducted mainly in western-industrialized countries and has often focused on individual difference variables like intelligence (e.g., Gonzalez, Thomas, & Vanyukov, 2005) and computer experience (Schaub, 2001) to explain performance variance. Recently, researchers recommended more focus on CPS strategies (Schoppek & Putz-Osterloh, 2003).

Surprisingly, as Weber and Hsee (2000) stated, the study of how culture influences problem solving and decision making has not received much attention. Psychinfo shows 16 peer-reviewed articles from 1984 to 2008 for the three keywords *culture*, *decision making*, and *cognition*. Although cultural research on reasoning, concepts, and inferences has increased in recent years (e.g., Medin et al., 2006; Nisbett, 2003), the study of culture and decision making and problem solving is still in its infancy.

Culture can be understood as implicit and explicit knowledge shared by a specific group of people and transmitted from generation to generation. A strong influence from culture might be expected as cultural environment has a significant impact on problem-solving knowledge. Indeed, some studies have shown cross-cultural differences in CPS (e.g., Strohschneider & Güss, 1999). Thus, the goal of our study was to assess both individual difference variables and CPS strategies and their influence on performance in different cultures.

Values are an aspect of cultural knowledge relevant to this study because they can be understood as abstract, transsituational goals that may act as guiding principles for

the selection of specific strategies in complex and novel problem situations.

This study focused on two value dimensions individualism–collectivism and power distance (e.g., Hofstede, 2001). Those two dimensions were assessed in four different relatively independent value preferences in previous studies: Horizontal individualism (HI), vertical individualism (VI), horizontal collectivism (HC), and vertical collectivism (VC). HI favors equality and focuses on oneself; VI accepts inequality and focuses on oneself; HC favors equality and focuses on the group; VC accepts inequality and focuses on the group (Singelis, Triandis, Bhawuk, & Gelfand, 1995; Triandis, Chen, & Chan, 1998). Previous research has shown that individualistic values were related to more planning and to a more action-oriented problem-solving strategy (Mann et al., 1998). Collectivist values were related to more caution and risk-avoidance and less action orientation (Ohbuchi, Fukushima, & Tedeschi, 1999). Low power distance was related to a higher desire for actions in decision making (Brockner et al., 2001).

The following analyses were intended to test the theoretical assumptions summarized in the path model (see Figure 1): 1) HI would be positively associated with action orientation, 2) VC would be negatively associated with action orientation, 3) Action orientation would mediate the relation between values and performance, 4) Action orientation would be positively associated with performance in WINFIRE and negatively with performance in COLDSTORE, 5) Planning would be positively associated with performance in WINFIRE, 6) Computer experience and intelligence would predict strategies and performance in both WINFIRE and COLDSTORE.

Method

Participants

Participants were 535 students from two different universities in each of the following countries: Germany (n = 104), the United States (n = 133), Brazil (n = 97), the Philippines (n = 104), and India (n = 97). Students were from the schools of arts and sciences, social sciences, and business. Samples were comparable according to course or major and gender. Females made up 63% of all participants. The age range was 18 to 49, with an average age of 22.1 years (*SD* = 4.44). None of the participants had taken part in other CPS experiments prior to this study.

To test for possible within-country variability, we compared the performance in the two microworlds between the participants of the two universities in every country. None of the differences was significant (*p*s < .11).

The countries were selected based on their differences in the two value dimensions studied. Germany and the United States have high individualistic values, Brazil and the Philippines have high collectivist values (Hofstede, 2001), and India has both individualistic and collectivist values (Sinha & Tripathi, 1994). The Philippines and India have high power distance, Brazil has medium, and the United States and Germany have low power distance values (Hofstede). Data were not complete for every participant due to computer problems, brownouts, no shows, and missing data on some survey items.

Instruments

Language. The questionnaires and instruction sheets for the microworlds were originally developed in English then translated from English into German and Brazilian Portuguese using the translation-backtranslation method. Translators were the trilingual author and graduate-level bilingual students in every country. As Indian and Filipino participants were bilingual and the mode of instruction was mostly English, the questionnaires were administered to them in English.

Cultural values. Horizontal and vertical collectivism and individualism were assessed with a Likert scale attitude measure developed by Singelis et al. (1995) consisting of eight items for each of the four dimensions, for example, "I prefer to be direct and forthright when discussing with people" (HI). The reliabilities were not ideal, but were similar to those of Singelis et al. and other studies (e.g., Kurman, 2003). We conducted confirmatory factor analysis for the four factor solution receiving the following goodness-of-fit indices: χ^2=1717.48 (df = 458), $p < .001$, χ^2/df = 3.75, GFI = .815, Std RMR = .086, RMSEA = .077, NNFI = .79. The fit indices are similar to those of Singelis et al., although they do not indicate adequate fit with the data. To assess construct validity, we also assessed HI, HC, VI, and VC with a decision scenario instrument consisting of 16 scenarios (Triandis et al., 1998). Correlations between the two scales were .22 for HI, .17 for VI, .24 for HC, and .36 for VC (*p*s < .001). These correlations were always higher than the correlations with the other subscales, thus indicating acceptable construct validity. We did not include the decision scenario instrument of Triandis et al. in further analyses because it yields nominal data and psychometric properties are not accessible in the literature or in our study.

WINFIRE. Performance in WINFIRE was measured by the percentage of protected area during each of its 111 cycles. In our study, the Cronbach alpha values for protected forest in cycles 42, 54, 90, and 111 was .80 for the overall sample. Overall, participants saved 52.33% (*SD*=11.69) of the forest at the end of the game. Without any intervention or commands from the firefighting commander, 45.18% of the forest would have been saved. Two strategies were identified from participants' saved computer files: action orientation, i.e., the total number of units moved during the entire microworld, indicating problem solving for the various fires; planning, i.e., the strategic distribution of trucks and helicopters even before the first fires started.

COLDSTORE. Performance in COLDSTORE was measured by the total deviations from the goal temperature. In our study, the Cronbach alpha values for the performance

variable in cycles 33, 66, and 100 was .84 for the overall sample. The fewer deviations from the goal temperature, the more successful the participant was. Action orientation was operationalized as total number of control wheel adjustments. It was not possible to operationalize planning adequately from the saved computer protocols.

Possible demographic covariates. Among other demographic variables, we also assessed years of computer experience due to its possibly variation across cultures and due to previous findings (Schaub, 2001).

Nonverbal intelligence. Additionally, the Test of Nonverbal Intelligence (TONI-3; Brown, Sherbenou, & Johnsen, 1997) was administered. The TONI was selected because it is relatively culture-free and it assesses nonverbal aspects of intelligence related to problem solving. The TONI-3, which takes about 15 minutes to complete, is a language-free test that assesses abstract reasoning and problem solving with 45 abstract-figural items assessing, for example, classification, analogous reasoning, induction, deduction, and detail recognition. The test has been validated in various ethnic groups and with several other intelligence tests. Retest reliabilities ranged from .79 to .95, and Cronbach alpha values were in the .90s (Brown et al.).

Procedure

The author collected data in the five countries over a 3-year period with an on site team in each country. Data were collected in group sessions (2 hours) and individual sessions where the WINFIRE and COLDSTORE microworlds were administered (2 hours). In the first meeting, participants filled out the demographic questionnaire, the two value surveys, and the TONI-3. In the individual meeting, each participant played WINFIRE and COLDSTORE and answered surveys regarding the microworlds. Instructions for each microworld were provided and test games were played before the actual microworld started. Each microworld lasted 12 minutes. All the decisions participants made were automatically saved to computer files.

Results

Descriptive Statistics

Descriptive statistics, including means, standard deviations, correlations, and reliabilities were analyzed (due to space limitations correlations cannot be shown). Table 2 shows means and standard deviations of all variables for the overall sample and for all cultural samples. One-way between-groups ANOVAs were conducted to test for cultural differences among the variables. The five countries differed in all variables significantly (ps <.001). Comparison of grand mean centered values data confirmed the postulated differences between countries.

Pan-cultural Path Analyses

Path analysis as a variant of structural equation modeling (SEM) was conducted using Mplus (Muthen & Muthen, 1998-2006). The compatibility of the specified model and the observed data were evaluated for both the WINFIRE and COLDSTORE models as strategy and performance variables differed between them. The Maximum Likelihood method was used to estimate path coefficients in the models. To evaluate the path models, several fit indexes were used following criteria guidelines on the interpretation of the indices (Hu & Bentler, 1999).

The overall pan-cultural unconstrained model for WINFIRE presented in Figure 1 shows adequate fit indices: $\chi^2(4) = 10.32$, $p = .04$; CFI = .968, TLI = .833, RMSEA = .054, and SRMR = .016. The proportion of the variability in action orientation explained by specific values (HI, VI, HC, VC), computer experience, and intelligence is 12% (R^2 = .116, $p < .001$). The proportion of variability in planning explained by specific values (HI, VI, HC, VC), computer experience, and intelligence is 9% (R^2 = .091, $p < .001$). Moreover, the proportion of the variability in WINFIRE performance that is accounted for by action orientation, planning, computer experience, and intelligence is 12% (R^2 = .123, $p < .001$).

The overall unconstrained model for COLDSTORE presented in Figure 2 shows very good fit indices: $\chi2(4) = 4.10$, p = .39; CFI = 1.000, TLI = .999, RMSEA = .007, and SRMR = .010. The proportion of the variability in action orientation explained by specific values (HI, VI, HC, VC), computer experience, and intelligence is 12% (R^2= .124, $p <$ .001). The proportion of the variability in COLDSTORE performance accounted for by action orientation, computer experience, and intelligence is 40% (R^2=.409, $p < .001$).

In WINFIRE, HI predicted action orientation positively and HC predicted it negatively. In COLDSTORE, VC predicted action orientation. In both models, computer experience and intelligence predicted strategies and strategies predicted performance. As expected, in COLDSTORE, more actions led to more deviations from the target temperature, i.e., worse performance. Computer experience predicted performance only in COLDSTORE, and intelligence predicted performance only in WINFIRE.

Path Analysis for Each Country

The models for the two microworlds were tested in all cultural groups separately. Overall, data fit the models reasonably well, indicating that the theoretical models hold in different cultural contexts (see Table 3). In WINFIRE, however, the German and Filipino TLI and RMSEA indicated inadequate fit with the data. In COLDSTORE, all but the German model showed excellent fit.

Table 1: Means and standard deviations of all variables for the five cultures and overall.

Dependent Variables	Overall	Brazil (1)	Germany (2)	India (3)	Philipp-ines (4)	United States (5)	*F*	df	η_p^2	Post hoc
Values										
HI	6.94	7.02	6.41	6.68	7.45	7.01	15.06***	4,	.11	4>1,5,3,2
	(1.04)	(0.95)	(1.04)	(1.15)	(0.88)	(0.95)		501		and 1,5>2
VI	5.23	4.30	4.83	5.83	5.75	5.34	23.91***	4,	.16	3,4,5 >1,2
	(1.40)	(1.28)	(1.29)	(1.17)	(1.24)	(1.42)		510		
HC	6.96	7.18	6.46	7.32	7.15	6.76	11.99***	4,	.09	3,1,4 >5,2
	(1.04)	(0.96)	(0.95)	(1.06)	(0.93)	(1.05)		510		
VC	5.75	4.96	4.56	6.93	6.81	5.55	93.90***	4,	.43	3,4>5>1,2
	(1.41)	(1.27)	(1.03)	(0.95)	(0.90)	(1.13)		503		
WINFIRE										
ActF	96.61	84.05	107.12	61.83	106.35	116.81	14.90***	4,	.12	5,2,4,1>3
	(57.18)	(51.64)	(40.57)	(47.62)	(63.85)	(61.34)		452		and 5,2>1
PlanF	3.60	3.38	5.05	1.74	4.08	3.64	15.74***	4,	.12	2,4,5,1>3
	(3.07)	(2.72)	(3.41)	(1.60)	(3.18)	(3.09)		462		and 2>5,1
PerfF	52.32	48.63	56.60	48.98	51.16	55.58	10.18***	4,	.08	2>4,3,1 and
	(11.68)	(5.71)	(14.56)	(8.63)	(10.74)	(13.65)		468		5>3,1
COLDST.										
ActCo	77.41	82.45	63.69	87.42	84.59	69.58	31.07***	4,	.21	3,4,1>5,2
	(20.29)	(15.51)	(23.12)	(10.94)	(14.30)	(22.98)		475		
PerfCo	593.52	667.12	395.80	727.86	675.32	507.13	33.99***	4,	.22	3,4,1>5>2
	(261.30)	(222.00)	(199.73)	(226.14)	(203.45)	(287.51)		474		
Control Variables										
Comp	2.18	2.32	2.55	1.46	1.84	2.58	43.21***	4,	.29	5,2,1>4>3
	(.77)	(0.76)	(0.50)	(0.61)	(0.70)	(0.64)		416		
Intell	35.69	34.87	38.99	33.49	35.73	35.55	16.86***	4,	.12	2>4,5,1,3
	(5.00)	(5.35)	(3.51)	(5.22)	(4.36)	(4.85)		501		and 4,5>3

Note. Standard deviations are provided in parentheses. * $p < .05$. ** $p < .01$. *** $p < .001$.

Table 2: Fit indexes for the proposed unconstrained WINFIRE and COLDSTORE models in each country.

Country	χ^2	df	*p*	CFI	TLI	RMSEA	SRMR	R^2 in perfor-mance	R^2 in activity	R^2 in planning
WINFIRE										
Brazil	2.16	4	.71	1.00	1.45	0.00	0.02	0.07	0.07	0.15
Germany	7.87	4	.10	0.87	0.31	0.09	0.04	0.13	0.13	0.06
India	3.39	4	.50	1.00	1.11	0.00	0.02	0.13	0.28	0.07
Philippines	9.18	4	.06	0.90	0.48	0.11	0.04	0.23	0.13	0.14
USA	5.42	4	.24	0.92	0.60	0.05	0.02	0.09	0.05	0.13
COLDSTORE										
Brazil	3.60	4	.46	1.00	1.06	0.00	0.03	0.22	0.13	
Germany	11.37	4	.03	0.84	0.49	0.13	0.05	0.39	0.05	
India	1.38	4	.85	1.00	1.90	0.00	0.02	0.16	0.06	
Philippines	2.90	4	.57	1.00	1.14	0.00	0.03	0.26	0.07	
USA	0.15	4	.99	1.00	1.24	0.00	0.00	0.42	0.08	

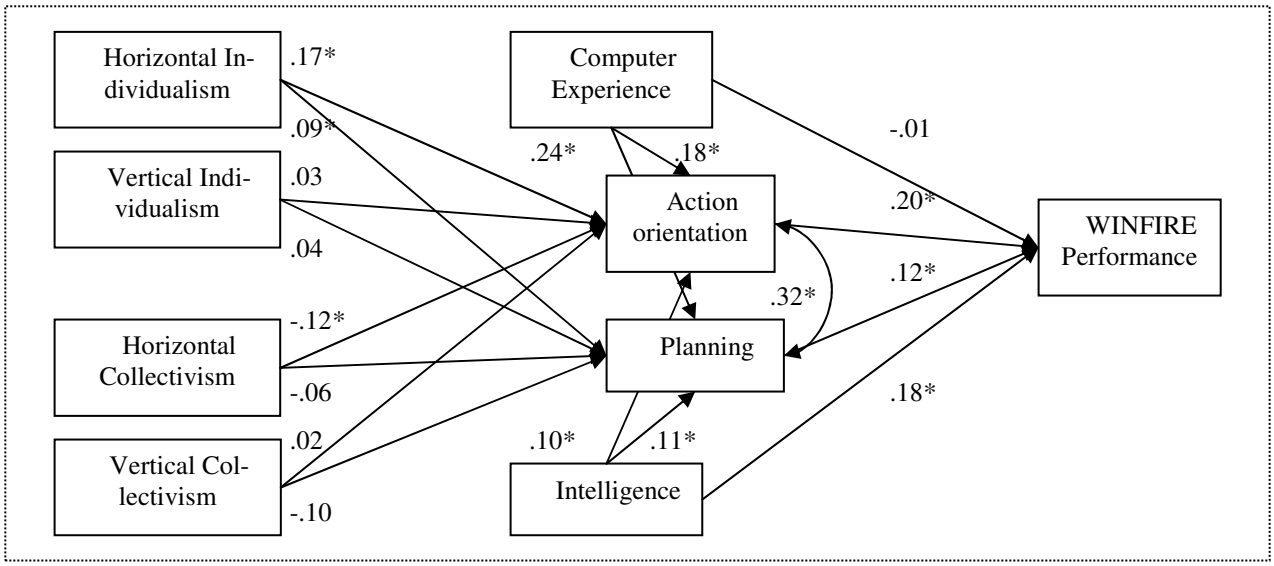

Figure 1: Path analysis indicating relationships among all variables in WINFIRE.
Note: Path loadings are standardized coefficients. Paths significant at *$p < .05$, **$p<.01$, and ***$p < .001$.

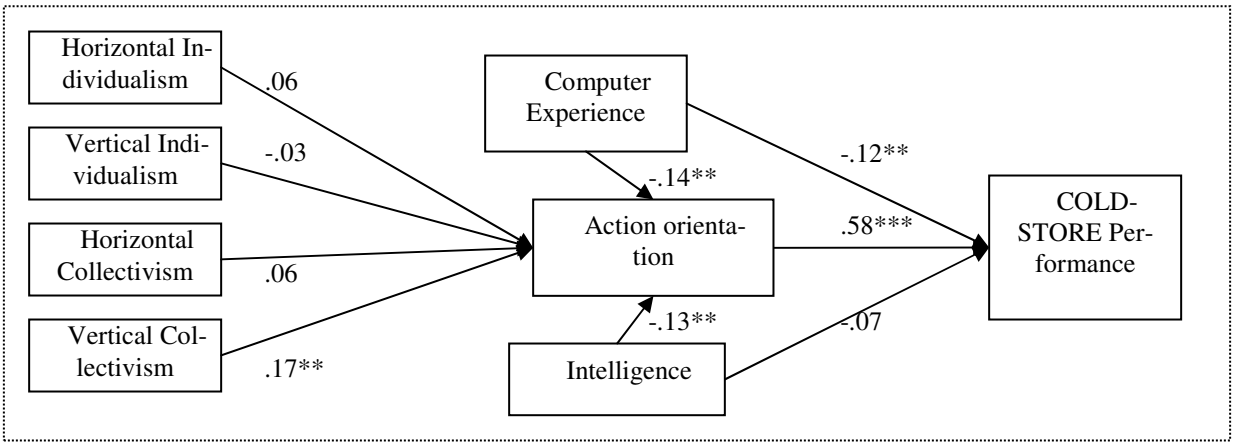

Figure 2: Path analysis indicating relationships among all variables in COLDSTORE.
Note: Path loadings are standardized coefficients. Paths significant at *$p < .05$, **$p<.01$, and ***$p < .001$.

Multiple Group Analysis

Path analyses with multi-group comparisons were then conducted to investigate the extent country moderated the relations specified in the models. Constrained and unconstrained models were compared. First we constrained all paths, but not the means and variances of the dependent variables, i.e., strategies and performance, as we expected cultural differences. Chi-square results were compared to the original model's chi square, and the significance of the difference was tested. Results from these analyses showed significant differences between constrained and unrestricted models in WINFIRE, χ^2_D (52) = 77.42, p = .01, and COLDSTORE, χ^2_D (28) = 38.33, p = .09.

In addition, we investigated which paths differed significantly between countries conducting pairwise comparisons for the 17 paths in WINFIRE and the 9 paths in COLDSTORE. Results showed at least two cross-country differences on seven paths in WINFIRE: from HC to activity, computer experience to activity, VI to planning, VC to planning, computer experience to performance, intelligence to performance, and planning to activity. In COLDSTORE, only the two paths from computer experience to activity and intelligence to activity differed significantly in more than two comparisons.

Discussion

The goal of this study was to test a theoretical model postulating that values influence strategies and strategies influence CPS performance in two different situations. Both WINFIRE and COLDSTORE models manifested a notable fit with the data for the overall pan-cultural model and for the models of each country (with the exception of the German models and the Filipino WINFIRE model). Six specific predictions for the path model were made:

1) HI would be positively associated with action orientation: Results showed that HI was only significantly related positively with performance in WINFIRE.

2) VC would be negatively associated with action orientation: Results showed that while HC and VC were negatively related to action orientation in WINFIRE, VC was positively related in COLDSTORE, contrary to our prediction. Paths did not differ significantly among countries, which could be related to task characteristics and the finding that collectivistic values lead to low action orientation in complex microworlds. The COLDSTORE microworld is not complex, yet is non-transparent. Participants with high VC values may feel comfortable dealing with non-transparence, leading them to be more active.
3) Action orientation would mediate between values and performance: Analyses showed that action orientation mediated the influence of HI and HC on performance in WINFIRE and VC on performance in COLDSTORE.
4) Action orientation would be associated positively with performance in WINFIRE and negatively in COLDSTORE: Results supported this prediction.
5) Planning would be positively associated with performance in WINFIRE: Results supported this prediction.
6) Computer experience and intelligence would predict strategies and performance in both WINFIRE and COLDSTORE. Consistent with previous studies, computer experience (Schaub, 2001) and intelligence (Gonzalez et al., 2005) were influential and predicted strategies in both microworlds in the expected direction, but not consistently. Path coefficients showed that strategies predicted performance better than computer experience and intelligence, showing the relevance of studying strategies in CPS as Schoppek and Putz-Osterloh (2003) suggested. CPS is a key ability for adapting to changes in the material and social environment. The environmental and social demands from which problem-solving strategies develop differ between cultures. Our study addressed specific aspects of culture that could be related to particular CPS strategies.

Notwithstanding potential limitations related to sample and method, the present study makes important advances in understanding cultural influences on CPS performance. The two models tested in this study provide support for a novel theoretical claim that abstract cultural values related to perception of self and others affect CPS strategies, in turn affecting performance. As the variance accounted for by particular strategy values was not too high, further research is needed to investigate other cultural variables that could influence CPS strategies and performance.

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