Supplementary Information
Coordination and balanced communication support collective problem-solving in organic teams

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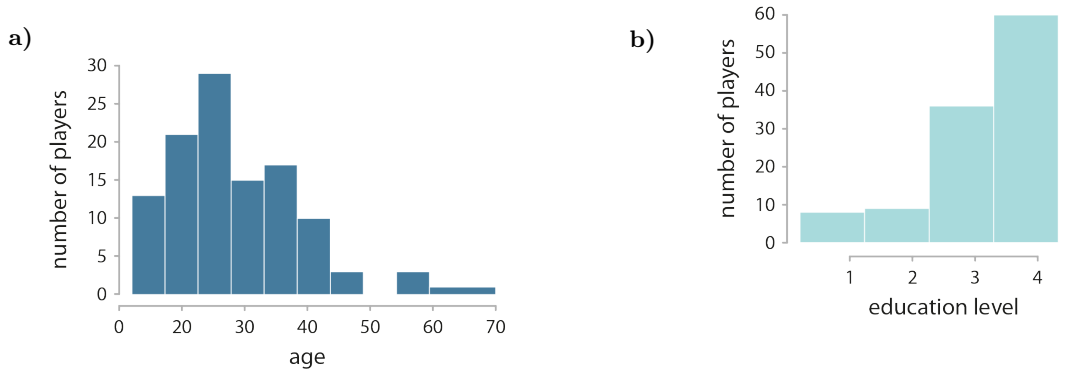


Figure S1: **Distribution of age and education.** Histograms of individual player characteristics across all participants. a) Age in years (dark teal bars), with the number of players on the vertical axis. b) Education level (light teal bars), coded on an ordinal scale from 1 (elementary school) to 4 (university degree), with the number of players on the vertical axis.

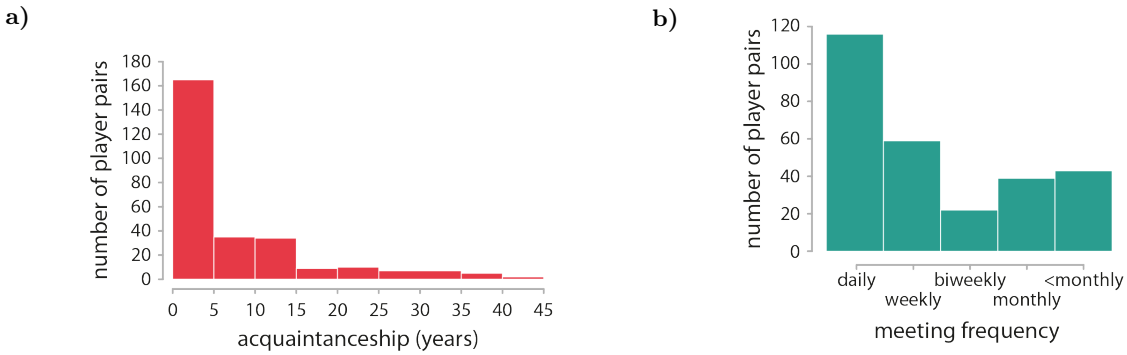


Figure S2: **Distribution of acquaintanceship and meeting frequency.** Histograms of pairwise relational characteristics across all player pairs. a) Length of acquaintanceship in years (red bars), with the number of player pairs on the vertical axis. b) Meeting frequency (green bars), grouped into ordered categories from daily to less than monthly, with the number of player pairs on the vertical axis.

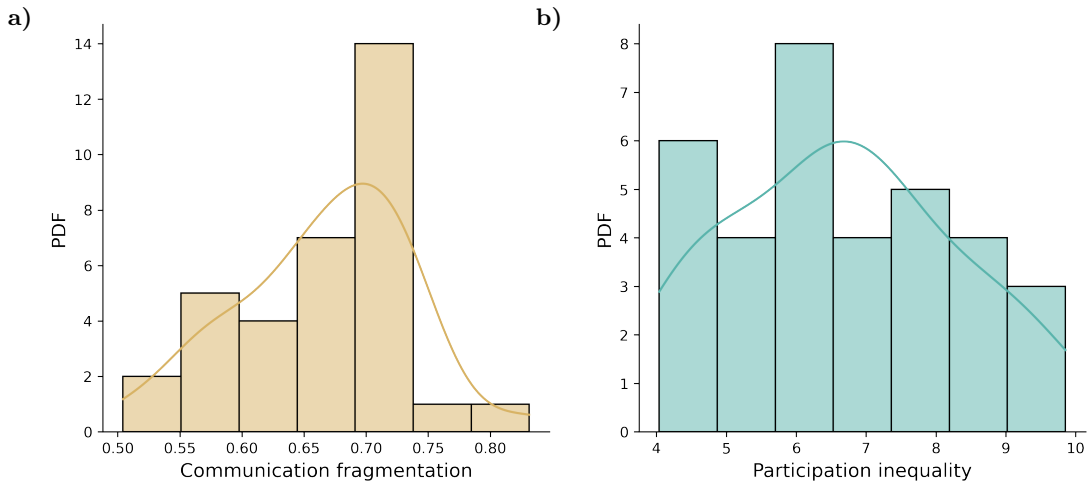


Figure S3: **Distribution of the communication fragmentation and participation inequality.** Task-level distributions of the two structural measures, each shown as a histogram with an overlaid kernel density estimate (KDE). The vertical axis shows the probability density (PDF). a) Communication fragmentation (number of connected components, normalized; beige bars with orange KDE curve). b) Participation inequality (standard deviation of the number of initiated communications; teal bars with teal KDE curve).

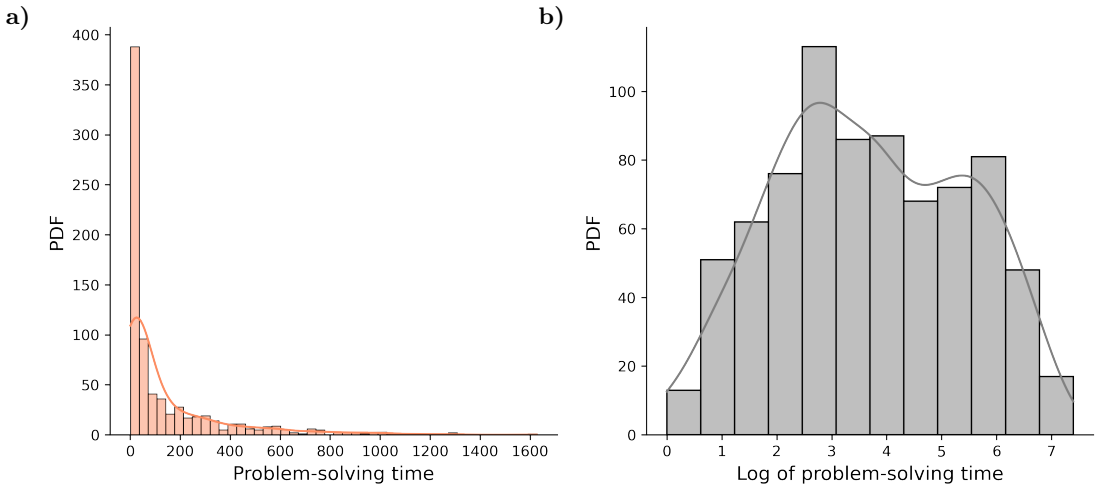


Figure S4: **Distribution of the problem-solving time.** Task-level distribution of the time taken to solve tasks, shown as a histogram with an overlaid kernel density estimate (KDE). a) Problem-solving time in seconds (salmon bars with orange KDE curve); the distribution is strongly right-skewed. b) The same variable on a log scale (gray bars with gray KDE curve), which is approximately symmetric and motivates the log link used in the Gamma generalized linear models (GLMs).

Table S1: **Summary Statistics**

	Behavior and performance (task-level)					
	Task type	Task-solving time	Communication fragmentation	Participation inequality	Ratio of positive interactions	Ratio of negative interactions
count	774.00	774.00	774.00	774.00	774.00	774.00
mean	0.34	140.01	0.66	6.55	0.08	0.05
std	0.47	225.38	0.14	8.96	0.12	0.11
min	0.00	1.00	0.20	0.00	0.00	0.00
25%	0.00	10.25	0.59	1.50	0.00	0.00
50%	0.00	36.00	0.68	2.87	0.03	0.00
75%	1.00	173.50	0.75	8.22	0.11	0.06
max	1.00	1627.00	0.99	57.15	1.00	1.00

	Demographics, relations and success (team-level)						
	Team Success	Team type (formal/informal)	Age (avg)	Gender diversity	Education (avg)	Acquaintanceship	Meeting frequency
count	34.00	34.00	34.00	34.00	34.00	34.00	34.00
mean	0.38	0.44	30.68	0.38	3.23	6.73	3.95
std	0.49	0.50	9.13	0.19	0.72	6.87	0.89
min	0.00	0.00	18.00	0.00	1.50	0.38	2.25
25%	0.00	0.00	22.81	0.38	2.64	2.69	3.18
50%	0.00	0.00	29.23	0.48	3.45	4.71	4.17
75%	1.00	1.00	36.75	0.50	4.00	8.31	4.58
max	1.00	1.00	50.50	0.50	4.00	35.08	5.00

COVARIANCE AND VARIATION INFLATION FACTOR ANALYSIS

Here, we present a covariance matrix and VIF analysis of the model variables. We also add the number of interactions. As Table S2 shows, communication fragmentation and participation inequality represent different, structural dimensions of team behavior than that of the mere volume of interactions.

Table S2: Covariance Matrix of Model Variables

	Education (avg)	Age (avg)	Gender diversity	Acquaintanceship (avg)	Task type (exploration/exploitation)	Meeting frequency (avg)	Team type (informal/formal)	Communication fragmentation	Participation inequality	*Number of initiated interactions*
Education (avg)	0.549145	3.901398	0.018657	1.163584	0.003874	-0.003863	-0.048262	-0.012913	0.189238	2.443511
Age (avg)	3.901398	78.730762	0.497798	30.958863	-0.185763	-0.575899	-0.422501	-0.128576	1.318624	33.574083
Gender diversity	0.018657	0.497798	0.061251	0.050409	-0.003073	-0.083736	0.006001	0.002536	-0.067618	0.214252
Acquaintanceship (avg)	1.163584	30.958863	0.050409	39.800321	-0.186812	0.854946	-1.338464	-0.145554	2.673649	41.356623
Task type (exploration/exploitation)	0.003874	-0.185763	-0.003073	-0.186812	0.225446	0.006795	0.006931	0.005014	1.963633	26.071909
Meeting frequency (avg)	-0.003863	-0.575899	-0.083736	0.854946	0.006795	0.761969	-0.107410	-0.014086	0.006926	0.650125
Team type (informal/formal)	-0.048262	-0.422501	0.006001	-1.338464	0.006931	-0.107410	0.244701	0.012454	0.001447	-0.186924
Communication fragmentation	-0.012913	-0.128576	0.002536	-0.145554	0.005014	-0.014086	0.012454	0.019029	0.023920	0.384384
Participation inequality	0.189238	1.318624	-0.067618	2.673649	1.963633	0.006926	0.001447	0.023920	80.343316	901.318503
Number of initiated interactions	2.443511	33.574083	0.214252	41.356623	26.071909	0.650125	-0.186924	0.384384	901.318503	13864.303875

As the VIF values are below 5, there is no significant multicollinearity present.

Table S3: Variance Inflation Factors

Feature	VIF
Constant	150.546637
Education (avg)	1.644407
Age (avg)	2.414019
Gender diversity	1.258951
Acquaintanceship (avg)	1.948923
Task type (exploration/exploitation)	1.328183
Meeting frequency (avg)	1.310300
Team type (informal/formal)	1.378792
Communication fragmentation	1.070807
Participation inequality	3.809982
Number of initiated interactions	3.848584

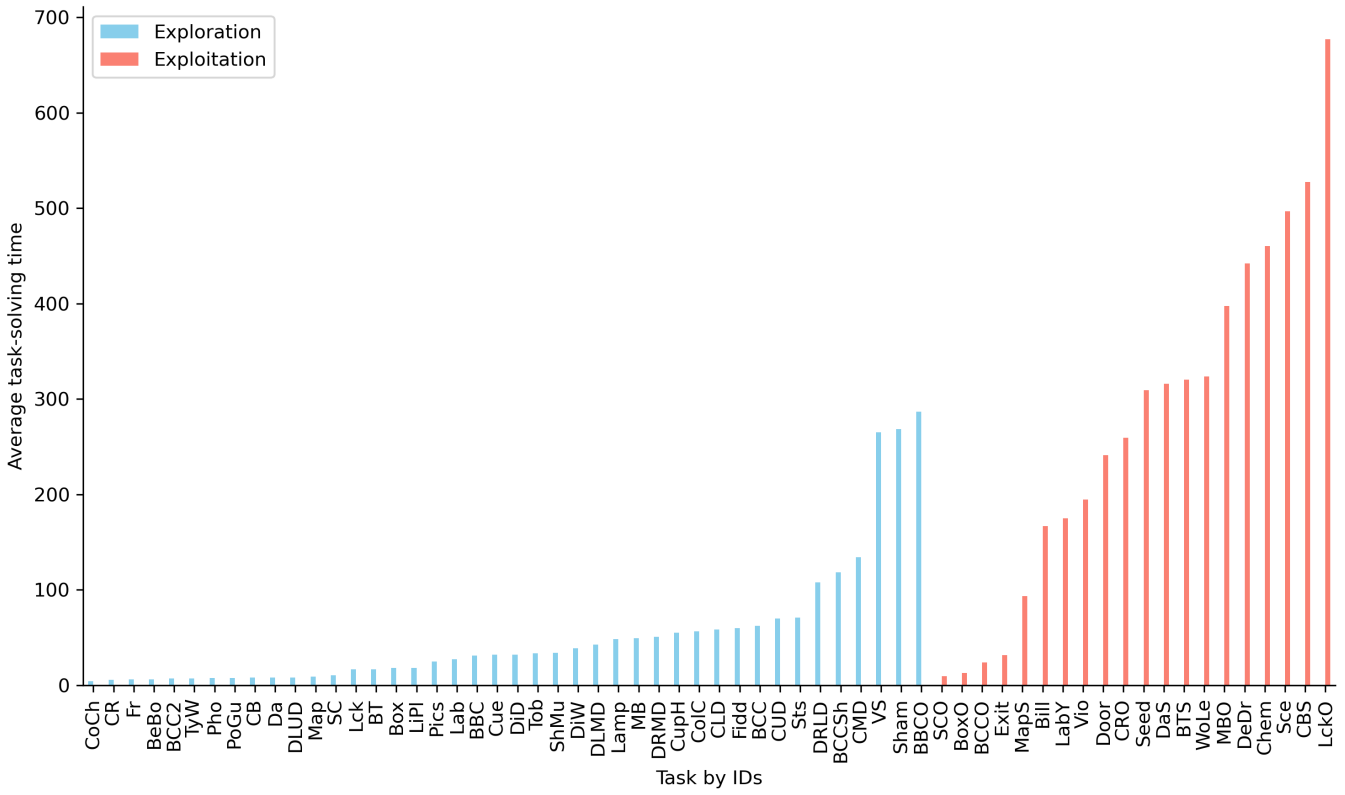


Figure S5: **Average task-solving time by task type.** Mean time in seconds to solve each task, one bar per task, ordered within type. Exploration tasks are shown in light blue and exploitation tasks in red. Task abbreviations on the horizontal axis are unique task IDs.

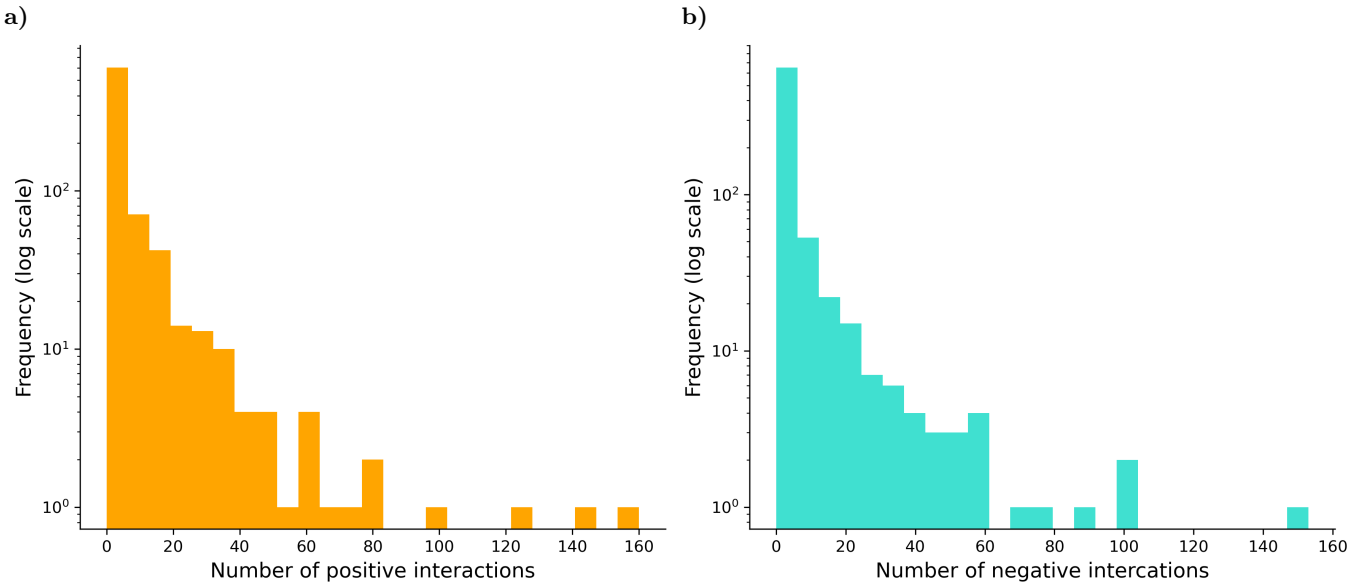


Figure S6: **Distribution of signed interactions.** Team-level distribution of emotionally loaded interactions, with frequency on a logarithmic vertical axis. a) Number of positive interactions per team (orange bars). b) Number of negative interactions per team (turquoise bars). Both distributions are strongly right-skewed.

Predictors	**Model 1**	**Model 2**	**Model 3**
	Time of task	*Time of task*	*Time of task*
(Intercept)	3.88***	1.05*	0.78*
	(0.52)	(0.41)	(0.37)
Task type (0=exploration, 1=exploitation)	1.59***	0.62***	0.53
	(0.13)	(0.10)	(0.50)
Age (average)	0.00	0.02*	0.02**
	(0.01)	(0.01)	(0.01)
Gender diversity	0.12	0.19	0.17
	(0.40)	(0.27)	(0.24)
Education (average)	0.00	0.00	-0.00
	(0.11)	(0.07)	(0.07)
Acquaintanceship (average)	0.03*	0.01	-0.01
	(0.01)	(0.01)	(0.01)
Meeting frequency (average)	-0.07	-0.01	0.00
	(0.07)	(0.05)	(0.04)
Team type (0=informal, 1=work)	0.26	0.09	-0.07
	(0.17)	(0.11)	(0.10)
Communication fragmentation		2.24***	1.84***
		(0.31)	(0.30)
Participation inequality		0.14***	0.27***
		(0.01)	(0.01)
Communication fragmentation*task type			1.88**
			(0.72)
Participation inequality*task type			-0.19***
			(0.01)
Observations	774	774	774
R^2 Nagelkerke	0.295	0.656	0.731

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table S4: **Modeling the effect of network structure on team performance.** Coefficient estimates from Gamma GLMs with a log link predicting problem-solving time. Model 1 presents the baseline with team demographics and task type, Model 2 investigates the direct effect, Model 3 the interaction effect of communication fragmentation and participation inequality with task type on problem–solving time.

Predictors	**Model 4**	**Model 5**	**Model 6**
	Time of task	*Time of task*	*Time of task*
(Intercept)	0.42	0.34	0.24
	(0.36)	(0.38)	(0.38)
Task type (0=exploration, 1=exploitation)	0.54	0.60	0.93
	(0.47)	(0.47)	(0.48)
Age (average)	0.02**	0.02**	0.02***
	(0.01)	(0.01)	(0.01)
Gender diversity	0.26	0.26	0.22
	(0.23)	(0.23)	(0.22)
Education (average)	0.02	0.02	0.03
	(0.06)	(0.06)	(0.06)
Acquaintanceship (average)	-0.01	-0.01	-0.01
	(0.01)	(0.01)	(0.01)
Meeting frequency (average)	0.01	0.01	0.02
	(0.04)	(0.04)	(0.04)
Team type (0=informal, 1=work)	0.02	0.02	0.02
	(0.10)	(0.10)	(0.10)
Communication fragmentation	1.88***	1.99***	1.99***
	(0.28)	(0.32)	(0.32)
Participation inequality	0.27***	0.27***	0.27***
	(0.01)	(0.01)	(0.01)
Positive communication	0.64*	0.75	0.77
	(0.28)	(1.14)	(1.13)
Negative communication	1.20***	2.69*	2.80*
	(0.33)	(1.14)	(1.14)
Communication fragmentation*task type	1.86**	1.77**	1.42*
	(0.68)	(0.68)	(0.68)
Participation inequality*task type	-0.19***	-0.19***	-0.19***
	(0.01)	(0.01)	(0.01)
Communication fragmentation*positive communication		0.10	0.52
		(1.70)	(1.70)
Communication fragmentation*negative communication		-2.31	-2.49
		(1.56)	(1.56)
Participation inequality*positive communication		-0.05	0.05
		(0.04)	(0.05)
Participation inequality*negative communication		0.02	-0.14
		(0.06)	(0.07)
Positive communication*task type			-3.20***
			(0.75)
Negative communication*task type			3.75**
			(1.15)
Observations	774	774	774
R^2 Nagelkerke	0.736	0.736	0.742

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table S5: **Modeling the effect of emotional load of communication on team performance.** Point estimate plot for statistical models predicting problem-solving time. Model 4 presents the direct effect of emotionally loaded (positive/negative) communication. Model 5 investigates the interaction effect of emotional communication and the structure of communication (fragmentation and participation inequality). Model 6 examines the combined effect of emotional communication and task type on problem-solving.

CLUSTERED STANDARD ERRORS

As tasks from the same team are not truly independent, unobserved team-level factors such as shared history might make a team's tasks resemble one another, which can deflate standard errors of the models. However, in our data, the team a task belongs to explains very little of the variation in task-solving time. Almost all of it (about 97%) occurs within teams rather than between them, leaving an intraclass correlation of only 3.2%. With an average of 23 tasks per team, even this small correlation understates standard errors by roughly 30% on average, so we refit each model with standard errors clustered by team (Table S6). Coefficients are unchanged; significance levels are not. Communication fragmentation, participation inequality, and their interactions with task type remain significant, including the cross-over interaction between participation inequality and task type. Average age falls just below significance, consistent with its borderline status under the original model. Given the small number of clusters, results near the significance threshold should be read with caution.

We applied the same clustering correction to the models including emotional load (Table S7). The structural effects are again unaffected. Communication fragmentation, participation inequality, and their interactions with task type remain significant. The emotional load terms are more sensitive. The main effects of positive and negative communication, significant under the original standard errors, no longer reach significance once we account for the dependence within teams. Their interactions with task type (Model 6) persist but weaken; the effect of positive communication on exploitation remains significant, while the corresponding effect of negative communication remains significant but only narrowly so, and we interpret it cautiously given the small number of clusters. Therefore, we treat the task dependent role of emotional communication as the more robust finding and interpret the direct main effects with corresponding caution.

Predictors	**Model 1**	**Model 2**	**Model 3**
	Time of task	*Time of task*	*Time of task*
(Intercept)	3.88***	1.05	0.78
	(0.60)	(0.63)	(0.56)
Task type (0=exploration, 1=exploitation)	1.59***	0.62***	0.53
	(0.13)	(0.12)	(0.48)
Age (average)	0.00	0.02	0.02
	(0.01)	(0.01)	(0.01)
Gender diversity	0.12	0.19	0.17
	(0.40)	(0.35)	(0.38)
Education (average)	0.00	0.00	-0.00
	(0.12)	(0.11)	(0.11)
Acquaintanceship (average)	0.03**	0.01	-0.01
	(0.01)	(0.01)	(0.01)
Meeting frequency (average)	-0.07	-0.01	0.00
	(0.11)	(0.11)	(0.09)
Team type (0=informal, 1=work)	0.26	0.09	-0.07
	(0.19)	(0.19)	(0.18)
Communication fragmentation		2.24***	1.84***
		(0.50)	(0.49)
Participation inequality		0.14***	0.27***
		(0.01)	(0.02)
Communication fragmentation*task type			1.88**
			(0.63)
Participation inequality*task type			-0.19***
			(0.03)
Observations	774	774	774
Teams (clusters)	34	34	34
R^2 Nagelkerke	0.295	0.656	0.731

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table S6: **Modeling the effect of network structure on team performance.** Coefficient estimates from Gamma GLMs with a log link predicting problem-solving time, with cluster-robust standard errors (clustered by team; 34 clusters) in parentheses. Model 1 presents the baseline with team demographics and task type; Model 2 adds the main effects of communication fragmentation and participation inequality; Model 3 adds their interactions with task type.

Predictors	**Model 4**	**Model 5**	**Model 6**
	Time of task	*Time of task*	*Time of task*
(Intercept)	0.42	0.34	0.24
	(0.60)	(0.60)	(0.59)
Task type (0=exploration, 1=exploitation)	0.54	0.60	0.93
	(0.48)	(0.44)	(0.50)
Age (average)	0.02	0.02	0.02
	(0.01)	(0.01)	(0.01)
Gender diversity	0.26	0.26	0.22
	(0.41)	(0.41)	(0.40)
Education (average)	0.02	0.02	0.03
	(0.11)	(0.11)	(0.11)
Acquaintanceship (average)	-0.01	-0.01	-0.01
	(0.01)	(0.01)	(0.01)
Meeting frequency (average)	0.01	0.01	0.02
	(0.10)	(0.10)	(0.10)
Team type (0=informal, 1=work)	0.02	0.02	0.02
	(0.18)	(0.17)	(0.17)
Communication fragmentation	1.88***	1.99***	1.99***
	(0.48)	(0.42)	(0.42)
Participation inequality	0.27***	0.27***	0.27***
	(0.02)	(0.02)	(0.02)
Positive communication	0.64	0.75	0.76
	(0.55)	(2.60)	(2.94)
Negative communication	1.20	2.69	2.80
	(0.74)	(4.27)	(3.90)
Communication fragmentation*task type	1.86**	1.77**	1.42*
	(0.63)	(0.58)	(0.61)
Participation inequality*task type	-0.19***	-0.19***	-0.19***
	(0.03)	(0.03)	(0.03)
Communication fragmentation*positive communication		0.10	0.52
		(3.73)	(4.28)
Communication fragmentation*negative communication		-2.31	-2.49
		(5.57)	(5.06)
Participation inequality*positive communication		-0.05	0.05
		(0.09)	(0.09)
Participation inequality*negative communication		0.02	-0.14
		(0.08)	(0.10)
Positive communication*task type			-3.20*
			(1.35)
Negative communication*task type			3.75*
			(1.89)
Observations	774	774	774
Teams (clusters)	34	34	34
R^2 Nagelkerke	0.736	0.736	0.742

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table S7: **Modeling the effect of emotional load of communication on team performance.** Coefficient estimates from Gamma GLMs with a log link predicting problem-solving time, with cluster-robust standard errors (clustered by team; 34 clusters) in parentheses. Model 4 presents the direct effect of emotionally loaded (positive/negative) communication. Model 5 investigates the interaction effect of emotional communication and the structure of communication (fragmentation and participation inequality). Model 6 examines the combined effect of emotional communication and task type on problem-solving.

NONPARAMETRIC BOOTSTRAP FOR EMPIRICAL CONFIDENCE INTERVALS

We constructed empirical 95% confidence intervals for the regression coefficients in Models 1-3 using a nonparametric bootstrap with 1000 resamples. For each bootstrap, we refit the same Gamma-log GLM as in the main text and recorded the coefficient vector. For each coefficient, we report the percentile interval. Figure S7 plots the median (dot) and the empirical 95% interval (horizontal bar) on the log (link) scale for direct comparison with Figure 2a. The intervals are nearly indistinguishable from the main Wald intervals, which is consistent with the asymptotic normality of GLM estimates on the link scale.

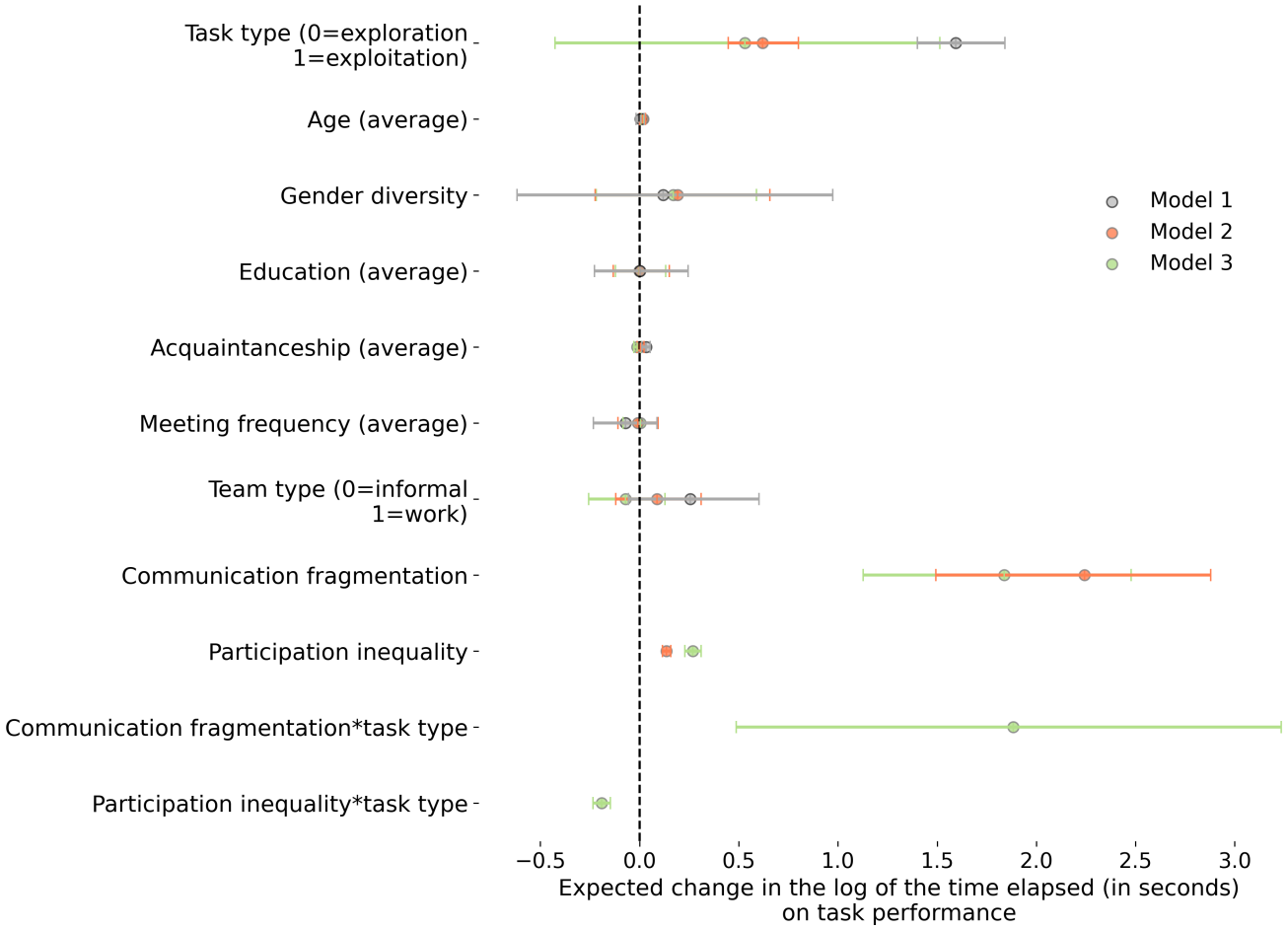


Figure S7: **Empirical (bootstrap) 95% confidence intervals (CIs) for the Gamma generalized linear model (GLM) coefficients on the log (link) scale.** Points show bootstrap medians and horizontal bars the 2.5–97.5th percentile interval across $B = 1000$ resamples; the dashed vertical line marks zero. Estimates are shown for Model 1 (gray), Model 2 (orange) and Model 3 (green). The intervals are nearly indistinguishable from the Wald intervals in Figure 2a.

Then, we transformed each bootstrap draw to percentage change, and show the empirical percentile interval and median. Because the exponential is nonlinear, the intervals are asymmetric around the median, which is expected on the original scale.

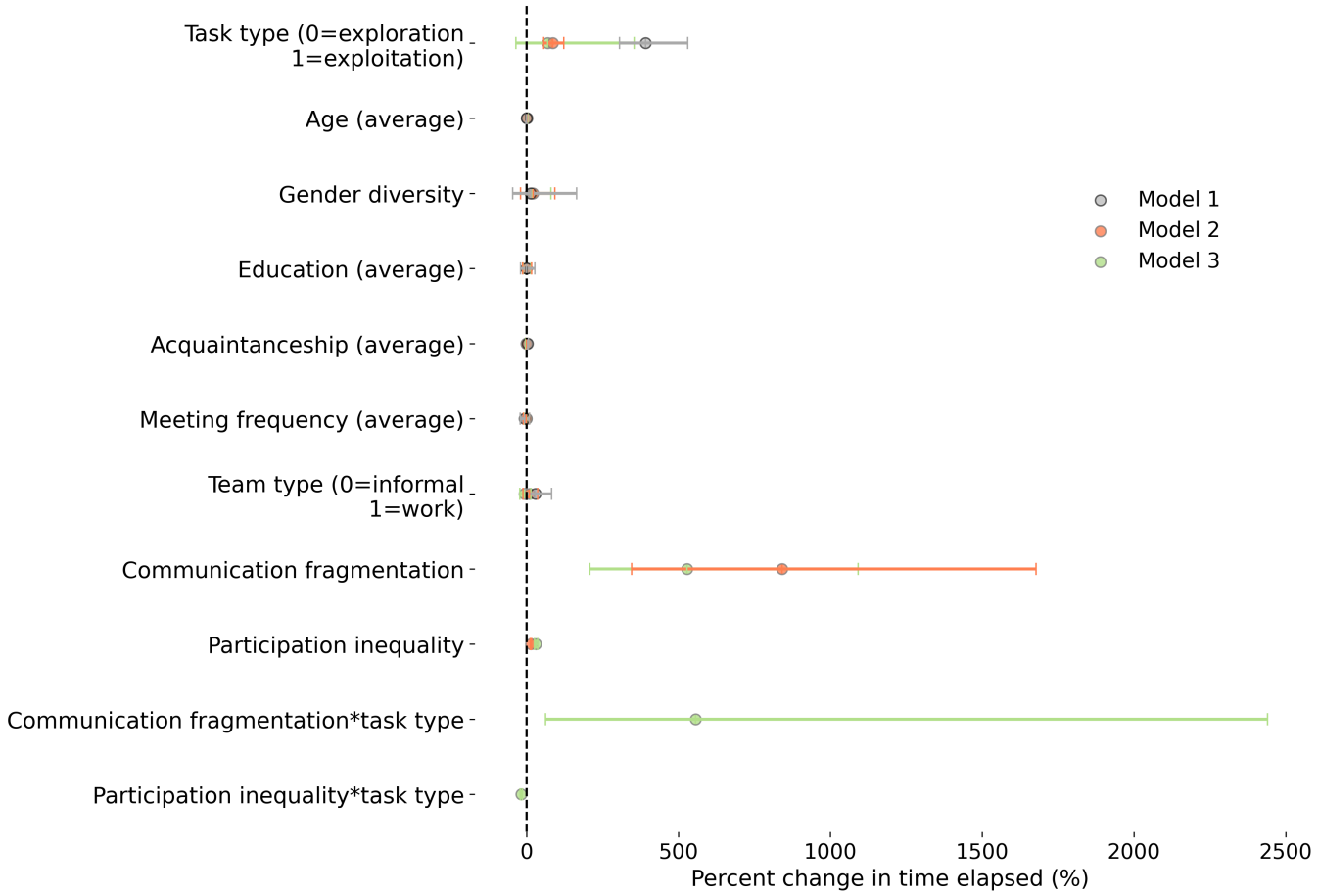


Figure S8: **Empirical (bootstrap) 95% confidence intervals (CIs) for the Gamma GLM coefficients expressed as percent change in expected time.** Points show bootstrap medians and horizontal bars the 2.5–97.5th percentile interval across $B = 1000$ resamples, for Model 1 (grey), Model 2 (orange) and Model 3 (green); the dashed vertical line marks zero. Because the transformation is nonlinear, the intervals are asymmetric around the median.

Table S8: **Modeling team success.** The task-solving time does not predict the binary success/fail outcome, as successful teams are not quicker problem-solvers in general, considering the entire, 60-minute game.

Variable	Coef.	Std. Err.	z	p	[0.025	0.975]
Intercept	-0.3921	0.087	-4.532	0.000	-0.562	-0.223
Problem-solving time	-0.0002	0.000	-0.712	0.477	-0.001	0.000

TESTING FOR DIFFERENT CONTROLS

Table S9: GLM regression results – number of communication added

Variable	Coef.	Std. Err.	z	p	[0.025	0.975]
Intercept	1.0291	0.289	3.560	0.000	0.463	1.596
Task type (exploration/exploitation)	0.4356	0.070	6.222	0.000	0.298	0.573
Age (avg)	0.0087	0.005	1.732	0.083	-0.001	0.019
Education (avg)	0.0249	0.052	0.483	0.629	-0.076	0.126
Gender diversity	0.1823	0.189	0.963	0.336	-0.189	0.553
Acquaintanceship (avg)	0.0112	0.007	1.719	0.086	-0.002	0.024
Meeting frequency (avg)	0.0025	0.035	0.072	0.943	-0.066	0.071
Team type (informal/formal)	0.1729	0.081	2.143	0.032	0.015	0.331
Communication fragmentation	2.2043	0.216	10.184	0.000	1.780	2.629
Participation inequality	0.0413	0.006	6.599	0.000	0.029	0.054
Number of initiated interactions	0.0085	0.000	17.750	0.000	0.008	0.009

The inclusion of the number of initiated interaction/link count does not modify the results – both our key measures remain statistically significant with stronger effect sizes than that of the mere volume of communication.

Table S10: GLM regression results – duration of communication added

Variable	Coef.	Std. Err.	z	p	[0.025	0.975]
Intercept	1.1926	0.276	4.317	0.000	0.651	1.734
Task type	0.4487	0.067	6.730	0.000	0.318	0.579
Communication fragmentation	2.3711	0.207	11.472	0.000	1.966	2.776
Participation inequality	0.0343	0.006	5.674	0.000	0.022	0.046
Age (avg)	0.0041	0.005	0.845	0.398	-0.005	0.014
Education (avg)	0.0215	0.049	0.437	0.662	-0.075	0.118
Gender diversity	0.0753	0.181	0.417	0.677	-0.279	0.429
Acquaintanceship (avg)	0.0098	0.006	1.573	0.116	-0.002	0.022
Meeting frequency (avg)	-0.0126	0.033	-0.378	0.705	-0.078	0.053
Team type	0.1102	0.077	1.430	0.153	-0.041	0.261
Duration of communication	0.0030	0.000	19.494	0.000	0.003	0.003

We tested whether the duration of communication have a similarly sized effects than that of our structural variables, communication fragmentation and participation inequality. As the models show, it has only a tiny effect leaving the original results intact.

Switching rate between task types. To test whether the difference in responsiveness reflects more frequent alternation between task types, we computed each team's transition rate which is the proportion of consecutive solved tasks (in order of completion) for which the task type changed. Successful teams showed a numerically higher transition rate than failed teams, but this difference was small and not statistically significant (rpb = 0.12, p = 0.49), and it disappeared entirely when restricted to points where both task types were available (p = 0.71). We therefore find no reliable evidence that switching frequency distinguishes successful teams.

Table S11: **Model comparison with information criteria.** Log-likelihood, number of estimated parameters (k), Nagelkerke's R^2, and the Akaike and Bayesian information criteria for the six Gamma GLMs, all fitted on the same $N = 774$ tasks. ΔAIC and ΔBIC are differences from the best-scoring model under each criterion (lower values = stronger support); the best value under each criterion is shown in bold. k includes the estimated Gamma dispersion parameter.

Model	k	$\log L$	Nagelkerke R^2	AIC	BIC	ΔAIC	ΔBIC
Model 1	9	−4397.56	0.295	8813.11	8854.98	906.77	872.52
Model 2	11	−4061.03	0.656	8144.06	8195.23	237.72	212.78
Model 3	13	−3960.85	0.731	7947.70	8008.17	41.35	25.72
Model 4	15	−3941.34	0.736	7912.68	**7982.46**	6.34	**0.00**
Model 5	19	−3939.79	0.737	7917.58	8005.96	11.23	23.50
Model 6	21	−3932.17	0.742	**7906.35**	8004.03	**0.00**	21.57

ETHICAL RESEARCH DOCUMENTATION

Scanned copy of the study's ethics approval and informed consent materials.

Central European University
Budapest Hungary
CEU OFFICIAL DOCUMENT
F-1010-3 v 1305

CEU RESEARCH SUPPORT SCHEME

ANNEX 1 APPLICATION FORM

1. Type of research support request

X - Grant to Individual CEU Academic Staff Member (not exceeding €5,000)
☐ - Grant to Academic Unit (CEU Academic Departments and Schools, Research Groups and Research Centers)

2. Title of the proposed research

The micro-dynamics of problem-solving behavior

3. Department/Academic Unit

Department of Network and Data Science

4. Principal researcher (a permanent faculty member of CEU)

Prof. Balázs Vedres (DNDS)

5. Other researchers

Rebeka O. Szabó, Srebrenka Letina (PhD candidates DNDS with disciplinary background in sociology and psychology, respectively)

6. Start and end dates of the proposed project

01/09/2018 – 01/09/2019

7. Brief description of the proposed project, activities and expected results

Teams have become a popular organization form, since well-functioning task-focused groups are basic pillars of successful organizations. There is much interest in contemporary social and data science in understanding the network micro mechanisms in teams, and we aim to advance this new science of teams' with experimental approaches that generate extremely detailed data about interactions. Thus we operate at the new frontiers of data science and social psychology.
Most of the previous research of teams relied heavily on self-reported data yielding static and potentially biased information which can be inconsistent with actual behavior. Furthermore, as it has been argued by the most acknowledged researchers in the field of teams, interaction processes are the crucial indicators of the group performance, and they are completely overlooked by mainstream techniques.
We propose a novel approach that allows us to portray a nuanced, complex picture on problem-solving human behavior by measuring performance dynamics as it evolves in real-time, in a controlled environment.
Specifically, on the individual level, we will relate all micro events during task-solving activity in an online game with cognitive styles and personality, with the prospect of validating a new assessment tool. While on the team level, we will explore how temporal collaboration networks of small project teams relate to successful task performance by investigating their interaction patterns in two research settings: (I) Escape rooms, where all teams have to reach a well-defined goal by implementing a poorly-structured task; and (II) Interpretation of inkblot pictures, where groups should establish an agreement as soon as possible by performing a purely judgmental, unstructured task. In both cases, teams will be video recorded during the task-solving process in the same experimental situation, which will provide us with objective and fine-grained data with high time resolution.

1

We expect that homogeneous distribution of interactions across time and team members favors problem solving.
Based on our findings, we aim to provide practical implications to:
- develop new assessment tools to identify progressive strategies for creating successful teams;
- highlight processes that facilitate the emergence of optimal interaction patterns and improve team performance;

Funding is asked for:
- The number of small teams (4-5 people) to be analyzed is 184, meaning 184 hours of video records on group interactions. Coding of 1 record (1 hour) takes 5 hours to gain the raw data of the important parameters, as the sender, receiver, duration, content, and the timing of all the occurring pairwise interactions. (5*184=920 hours of coding). The funding is asked for research assistans (students) to transcribe in order to make this research feasible in a reasonable time interval. It should be noted, there is no non-manual (automatic) way of gaining the data we need out of the video records.
Proposed payment for 1 hour of coding: 4.5 euros. Cost of coding all records: 4140 euros. (4.5*920)
168 euros is asked for paying the escape room operator who has exclusive right and knowledge to handle escape room servers and devices.

- The on-line individual data collection from heterogeneous sample of individuals will be achieved with the usage of a crowdsourcing platform (Prolific, https://prolific.ac/). (N = approx. 350, duration of the on-line testing: 45 min). A video game already developed in professional assessment will be used. Each participant will be awarded with 2 euros (346*2=692 euros).

Please find the detailed work plan attached to this document.

This description should not exceed 1 page (possibly supplemented by Annexes and additional materials). It should outline (a) the scientific significance of the proposed project; (b) expected results including in terms of developing larger follow-up research or other strategic significance for CEU; (c) research activities for which funding is requested. Additional materials may be requested.

8. Does the project involve research ethical issues which need to be addressed in accordance with CEU Ethical Research Policy?

☐ - No
X - Yes
If yes, please, detail:

All the participants' data will be handled anonimously. The data collection does not include any identifiable data (such as surname or address). Video records on group activity will be made with the consent of the participants. Identification of the participants during data analysis will be based on randomly generated ID's or nicknames given by the participants to themselves.

9. Project administrator (with SAP licence)

Olga Peredi (DNDS coordinator)

10. Requested funding

Category	Amount
Video record (184 one-hour video records)	4140 EUR (22.5 EUR/record)
Techinal assistance for escape room-specific facilities (e.g.: servers, recording devices)	168 EUR (2 EUR/escape room session)
Individual online testing (total 346 participants)	692 EUR (2 EUR/participant)
TOTAL	5000 EUR

Add rows as necessary.

If research period exceeds one academic year please break down funds requested per academic year.
For details of funding period allowed and of eligible costs please see Research Support Scheme Policy.

Signatures by Head of the Department/Unit and Principal Researcher (not needed if sent by email):

Ref. No.:

Annex 3 to the Ethical Policy on Research:

Checklist on Ethical Issues in Research

This checklist is intended as a guide for CEU students/researchers in planning, designing and carrying research, and for applying approval to the Ethical Research Committee. The numbers in brackets indicate the relevant section of the Guidelines on Ethical Research. In case applying for approval from the Ethical Research Committee, provide explanatory answers that enable the Committee to assess whether the Guidelines were followed.

A. General information

1.Project name/Title of thesis/dissertation:
The micro-dynamics of problem-solving behavior
2. Name(s) of Applicant(s):
Rebeka O. Szabó, Srebrenka Letina
3. Contact information of applicants:
o.sz.rebu@gmail.com, sreb.letina.gmail.com
4. Department/Research Center:
Department of Network and Data Science
5. Research Supervisor (if applicable):
Prof. Balázs Vedres
6. Supervisor's contact information:
vedresb@gmail.com
7. Date by which a decision on this application is required in order that the project can proceed as planned, if approval is required:
21/09/2018
8. Expected date of completion:
01/09/2019
9. Abstract of the project/thesis/dissertation:

Ref. No.:

Teams have become a popular organization form, since well-functioning task-focused groups are basic pillars of successful organizations. There is much interest in contemporary social and data science in understanding the network micro mechanisms in teams, and we aim to advance this new science of teams' with experimental approaches that generate extremely detailed data about interactions. Thus we operate at the new frontiers of data science and social psychology.

Most of the previous research of teams relied heavily on self-reported data yielding static and potentially biased information which can be inconsistent with actual behavior. Furthermore, as it has been argued by the most acknowledged researchers in the field of teams, interaction processes are the crucial indicators of the group performance, and they are completely overlooked by mainstream techniques.

We propose a novel approach that allows us to portray a nuanced, complex picture on problem-solving human behavior by measuring performance dynamics as it evolves in real-time, in a controlled environment.

Specifically, on the individual level, we will relate all micro events during task-solving activity in an online game with cognitive styles and personality, with the prospect of validating a new assessment tool. While on the team level, we will explore how temporal collaboration networks of small project teams relate to successful task performance by investigating their interaction patterns in two research settings: (I) Escape rooms, where all teams have to reach a well-defined goal by implementing a poorly-structured task; and (II) Interpretation of inkblot pictures, where groups should establish an agreement as soon as possible by performing a purely judgmental, unstructured task. In both cases, teams will be video recorded during the task-solving process in the same experimental situation, which will provide us with objective and fine-grained data with high time resolution.

We expect that homogeneous distribution of interactions across time and team members favors problem solving.

Based on our findings, we aim to provide practical implications to:

- develop new assessment tools to identify progressive strategies for creating successful teams;
- highlight processes that facilitate the emergence of optimal interaction patterns and improve team performance.

B. Funding

10. Sources, researchers' and their organisation's financial interests and ethical issues in case of external funding:
Research Support Scheme

C. Participants
[If the research does not involve human subjects, go to section D.]

11. Does the study involve human subjects, and how? [Who will participate in the research? How will the subject/respondent group be chosen, what sampling techniques will be deployed? In which ways the participants will be involved? (2.1)
Yes, it does. *Escape room* participants are adults (18+) coming in groups to play the escape room game. We will only control the research subjects to age variance, since large age differences between group members are supposed to distort the interaction pattern of group activity. Participants' action will not be interfered to any extent. Their involvement is that if, and only if they explicitly give permission to us (by signing the consent form before the game) to access the video records made by the escape room operator on their group process, we will use these records to analyse their temporal communication network. *Inkblot task*: Participants will be recruited to solve a creative, open-ended task. Participants in this research setting apply for this task by signing the consent form that allows us to make and analyse video records on their group activity. *Individual on-line testing:* Participants recruited via the crowdsourcing platform (18+, males and females equally represented) will be asked to play an on-line game.
12. Are there potential benefits and hazards for the participants? [Are there risks to the subject entailed by involvement in the research? Have procedures been established for the care and protection of subjects? Will the participants be informed of possible risks and hazards?] (2.2 – 3.4)
Participants are not exposed to any physical, mental or financial risks.
13. Does the research involve any risks or pose danger to the researcher(s)? [If yes, what procedures will be adopted to minimize the risks? Have the health and safety guidelines relevant to the area and character of the research been consulted and implemented?] (4)
No.
14. Will all procedures ensuring that consent is informed be followed? [Including the possibility for withdrawing consent] (5.1)
Yes. Participants will be fully informed about all aspects of the research project, and will have the opportunity to ask for more information at any time of the data collection. Withdrawing the consent is possible before, and during both the individual on-line testing and the observed group activity. Please find the consent forms for the group experiments attached. Please find more details about the privacy policy and the terms and conditions of the crowdsourcing platform: https://www.prolific.ac/assets/docs/Participant_Terms.pdf https://www.prolific.ac/assets/docs/Prolific_privacy-policy.pdf
15. Are the recruitment procedures well planned, and risks of coercion considered? [Is there any sense in which subjects might be "obliged" to participate – or are volunteers being recruited? Does the participation of research involve financial or other remuneration?] (5.2)

Group tasks: Both naturally occurring participants in the escape rooms and the recruited ones in the case of the Inkblot task are not exposed to any pressure for participation or for giving permission for the usage of the records.

Individual on-line testing: The recruitment via a crowdsourcing platform (Prolific) is based on the financial payment to the participants. Potential participants will be informed about the duration and money awarded for their participation in advance, which will enable them to decide whether to participate or not.

16. Does the research involve incompetent adults, children, prisoners, other vulnerable groups or contexts where obtaining consent is impossible (i.e. public context, groups)?
[Which "consent"-procedures will be applied instead?] (5.3 – 5.5)

No, neither of the research settings require the participation of the above-mentioned groups.

17. Does the research involve deception?
[This will not be applicable to many studies. In case deception of participants is involved: how is the impossibility to employ alternative non-deceiving method of research justified? How is the deception integral to the viability of research? Will debriefing be employed and how will the participant's reactions influence the use of the data obtained?] (5.6 – 6)

No, not at all.

18. Will confidentiality and anonymity be secured?(8)
Yes. All the participants' data will be handled anonymously. None of these research designs involve the collection of any sensitive, confidential personal data, but only demographic data (and video records will be gathered if the consent is provided), and participants will be identified by randomly given ID's or nicknames chosen to themselves.
19. Will data protection and storage requirements be followed? (8)
Yes. The whole data collected in this project will be stored on safe CEU servers. Only researchers directly involved in this project will have access to this data.
20. Are there any plans for future use of the data beyond those already described?
The data may be shared with other non-profit academic organizations in the future to advance sharing practice in the field of social sciences.

D. Other Aspects:

21. Dissemination of findings: [What is the anticipated use of the data, forms of publication and dissemination of findings etc? In areas where information is jointly owned by participants as co-researchers attention should be paid to how they want to use the data.]
By the end of 2019., at least two publication will be submitted to peer-reviewed scientific journals, and oral presentations to at least two scientific conferences. The results will be presented on the official website of the Department of Network and Data Science. During the project, the preliminary results will be presented and discussed in front of the experts in the field, CEU students and interested researchers in form of the 45-minute presentation. It will take place twice in the academic year 2018/19.
22. Have you considered how to ensure that ethics considerations are reviewed as the project proceeds? [This is particularly relevant for projects that go on over a longer time period.]
Yes. All ethical questions will be handled as described above and will be additionally revisited by the scientific committee of the DNDS before the start of and during the data collection.
23. Is there any other information, which you think would be relevant to the reviewers', or your own, consideration of the ethical issues raised in this documentation?
No.

DECLARATION

The information supplied above is to the best of my knowledge and belief accurate.

Signature of Applicant: [signature] **Date:** 2018/08/26

[signatures]

SUPPORTING DOCUMENTS

Annex 3 to the Ethical Policy on Research

Ref. No.:

No.: 1 Title: Consent form for data usage – Escape Room

No.: 2 Title: Consent form for research participation – Inkblot task

No.: 3 Title: Research work plan

Annex 3 to the Ethical Policy on Research **Ref. No.:**

Outcome of the Ethical Review

The following section has to be filled in only when approval by the Ethical Research Committee is required (for example for the purposes of securing external funding); see Annex 2, Operational Rules, to the Ethical Research Policy.

Section 1 - Applicant/Lead Researcher

I confirm that all ethical issues involved in the project have been addressed. I consider my study conform with the expectations of ethical research and I apply for its approval.

Signature of Applicant/Lead Researcher: _____

Date: 2018/08/26

Section 2 - Supervisor (Head of Department, Director of Center etc.)

I have read the application and confirm that in my view all ethical issues involved in the project have been addressed.

Additional comments (optional):

Signature of Supervisor (Head of Department, Director of Center etc.): _____

Date: Aug. 27, 2018

Annex 3 to the Ethical Policy on Research **Ref. No.:**

Section 3 - Chair (or Acting Member)

The research proposal has been scrutinized and approved by the CEU Ethical Research Committee.

Additional comments (optional)

Signature of Chair (or Acting Member): _____

Date: Aug. 27, 2018

TRANSCRIPTION GUIDE

Quality aspects:

1. If you are **unsure about something**, anywhere (e.g.: who talks to whom, what the emotional charge of the communication is, etc.). – please, stop, and 1) revisit the matter later; 2) mark that part and **ask!**

2. This work requires the ability to stay focused on highly monotonous and repetitive tasks. Thus, **if** you feel **overwhelmed** and/or mentally exhausted, please stop! **=> relax** – rahter be late with the transcription than being inaccurate and put fatigue at the expense of precision!

WhatsApp/telefon: [redacted] *or after 7 pm:* [redacted]

Technical aspects:

Coding scheme - example

start time	end time	sender	receiver	charge	transcription
21:32:01	21:32:05	E	M	pos	text
21:32:01	21:32:05	E	D	pos	text
21:32:01	21:32:05	E	A	pos	text
21:32:06	22:32:09	D	A	neg	text
22:32:09	23:32:10	A	M	neutral	text
23:32:10	23:32:15	D	M	neg	text
---------- Cash register ----------					
21:32:12	21:32:16	M	D	pos	text

- An **interaction** is more than communication! For example, if a player shows something to another player without speaking, it is also considered an interaction, so we record it!

- Other non-verbal communication can be nodding; ‘reply’ for a request for example giving something to someone upon asking, etc. In contrast, natural moving in the room while searching for clues is not an interaction.

- An interaction is one train of thought. So, if someone starts talking but takes a tiny break (takes a breath – max. 1-2 seconds) and then continues while there is no other interaction in the meantime, it can be taken as one piece of interaction.

To be recorded:

1. start time
2. end time
3. sender
4. receiver
5. emotional charge
6. transcription (as much as possible)
7. general impression about the team (subjective)
8. sub-results

1. Start time:

Record the second in which the interaction starts.

2. End time:

The last second in which the interaction is ongoing. If somebody speaks until 21:32:09, so that in the 9th second they do not speak, the proper end time to be recorded is 21:32:08 as this is the last second the interaction is happening.

3-4. Sender-receiver:

- The sender and receiver/addressee of the interaction.
- If someone speaks to several people at the same time (a group interaction), we record in the same way as in the example above: E speaks to ME, D, and MA at the same time, because all three lines have the same start and end time of the interaction.

+ operator's call: we record when the interaction starts and ends, and who speaks with the operator

5. Emotional charge:

We classify the emotional charge of interactions into 3 categories: neutral , positive, negative.
For this, we focus on 1) valence, and 2) arousal.
Valence: pleasantness VS unplesentness
Arousal: intensity of the emotion

Neutral interactions are directed to the task itself and not to the relationships, AND are not emotionally loaded – no valence, no arousal.

Examples:
- finding of facts,
- emotionless communication,
- questions,
- showing something, etc.

Disagreement about the task is typically imply neutral interactions. If they get emotionally loaded , e.g., raised voice (high negative arousal), the interaction turns to be negative.
Example 1: „No, that won't work, it's a wrong calculation." – neutral, as it is task-focused and not emotionally loaded
Example 2: "You're being impossible, you don't cooperate." – negative, as person-related having negative emotional charge (valence and possibly arousal)

Positive interactions are all interactions

1) having positive emotional charge (valence and/or arousal)

2) not directed to the task itself but is rather related to interpersonal relationships positively

Examples: praise, laughing, joking, inspiration/emotional support, constructive, agreement, encouragement, acknowledgment

In general, every interaction that influence team spirit positively.

- Smooth collaboration between team members on a task does NOT account for positive interactions until these interactions are not emotionally loaded and/or not realted to relationships.
- Example: A: “we have to smell these tobaccos and identify them”
  Scenario 1: B: ‘wow, cool!’ with no positive arousal/enthusiasm in B’s voice, rather expresses “Noted.” => neutral,
  Scenario 2: “wow, cool!” with positive arousal/ enthusiasm => positive; although it is a task-related interaction, B’s reaction carries positive arousal

Negative interactions are all interactions

1) having negative emotional charge (valence and/or arousal)

2) not directed to the task itself but is rather related to interpersonal relationships negatively

Examples: disapproving, despising, trivialize, sarcastic/cynical, intentional ignoration of someone, dismissive, hostile, interrupting, expressing frustration

In general, every interaction that influence team spirit negatively.

- The word ‘no’ does not make the interaction automatically negative!
- E.g.: A: ‘here is a mongoose’ → B: ‘no, because look, it is the pipe…’. So, the interaction is tension-free, AND it is not a conflict of individual opinions, but a statement of fact (=task-related interaction without emotional load=neutral).

SPECIAL CASES:

1. Cutting into one's sentence while talking to another person, e.g. A cuts into S's sentence in a raised voice while S is talking to T. This is an important interaction that should be coded as two interactions: 1) S talks to T (probably neutral); 2) A sends a negative interaction to S (as A silences S).

2. Approval, but nervous reaction, e.g. raised voice => negative, strong negative arousal overwrites the content of the interaction. From neutral to negative in this case.

3. Talking to herself/himself OR any action which is not shared by someone: So it is not addressed to anyone, not a reaction to a previous action; when it is so quiet that nobody could
have a chance to hear it => both the sender and the receiver are the same person, e.g.: A talk to A (as (s)he grumbles something under her/his nose)

4. If there are parts with different emotional charge within the same sentence, it is coded in two separate lines with the corresponding emotional charge (note, this is very rare!)
E.g.: 'I think it's a pig, so you said pure nonsense first'. - although the first half of the sentence is a neutral statement with no emotional charge, it is used by the speaker to justify the second part of the sentence (that the addressee said a stupid thing). So, it is organically connected → overall, it is a negative interaction. (It could be separated if there is another interaction during the sentence since we transcribe in a chronological order.)

Another example:

A: ‘we can't even unload this’

- if (s)he grumbles under her/his nose, (s)he is the sender and the receiver
- if (s)he says it out loud, it is a derogatory (neg.) sentence addressed to everyone, and it is easy to see that it can be destructive to team spirit

6. Transcription:

Accurate description of communication (as much as possible). The text description should be as complete as possible! This includes the audible part of the conversation with the operator.

7. General impression on team spirit:

- as a team: lively / enthusiastic / innervated, etc.?
- as players: Everyone is equally motivated? Some are very enthusiastic, while others are quieter and more withdrawn?

8. Subtasks:

- For the exact subresult codes, please see the flowchart of the rooms and use the provided names of the subresults uniformly.

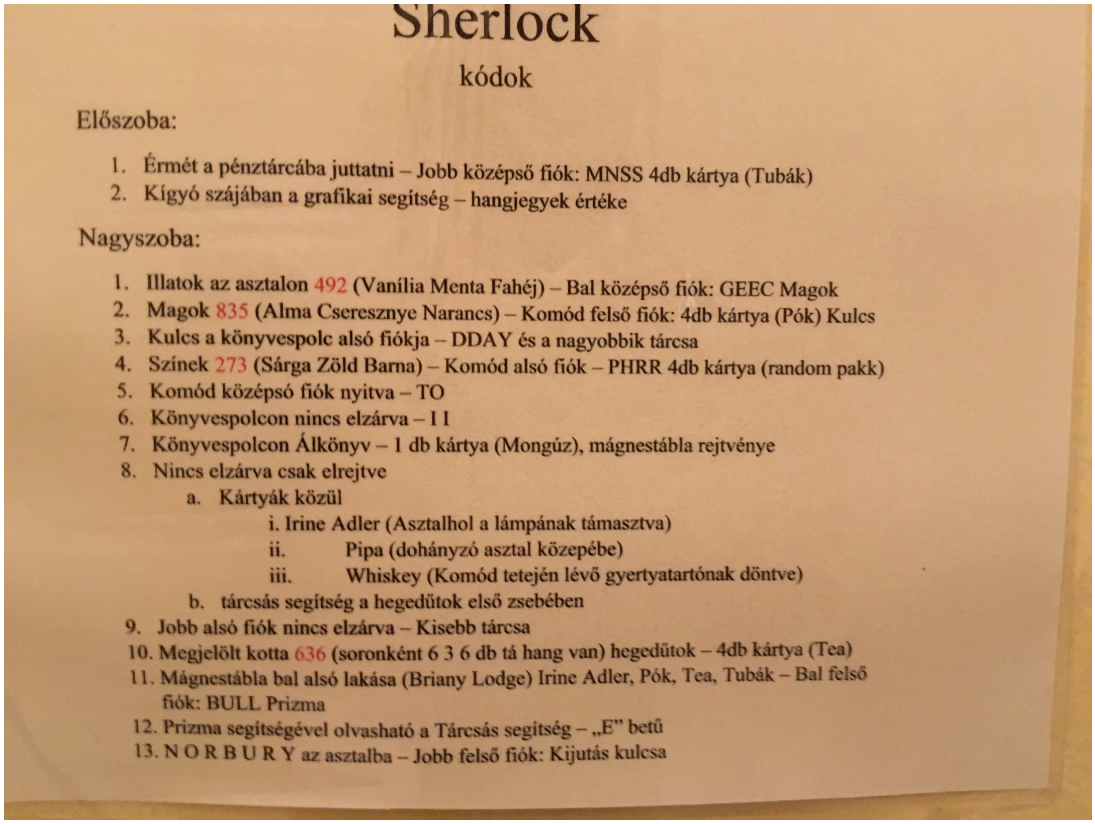
Note: If a participant does not seem to identify a clue (explored) as a relevant piece of information, it should not be recorded as a subtask solved. (A single occasion – a disk found in a drawer is placed back)

- Only a fully solved subtask can be considered as completed.

THE END/ESCAPE/EXIT:

The game & coding is over when the key of the door is found and identified for what it is for. (Sometimes they don't know what it opens for minutes.)

HELP FOR CODING SUBTASKS



Sherlock

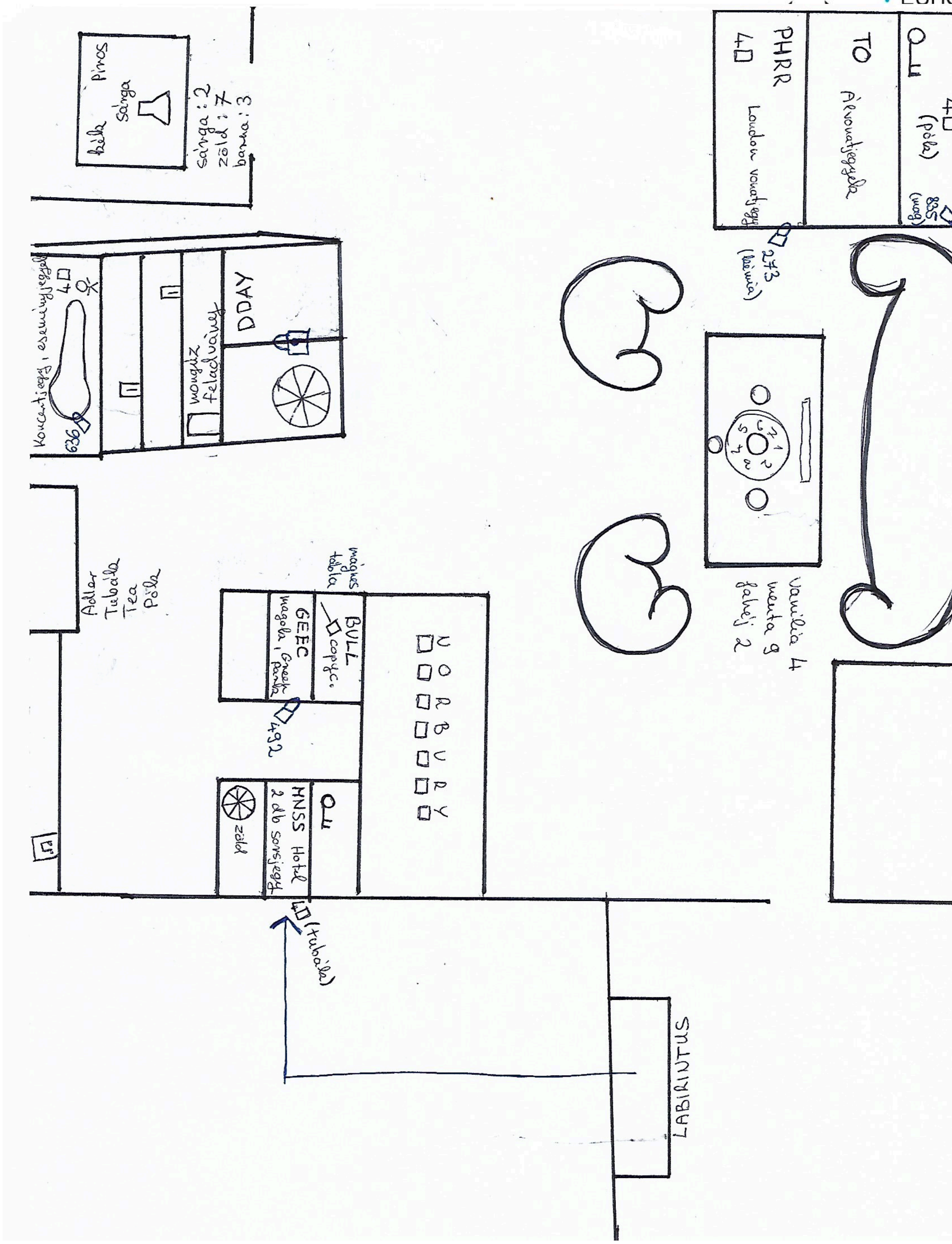
kódok

Előszoba:

1. Érmét a pénztárcába juttatni – Jobb középső fiók: MNSS 4db kártya (Tubák)
2. Kígyó szájában a grafikai segítség – hangjegyek értéke

Nagyszoba:

1. Illatok az asztalon 492 (Vanília Menta Fahéj) – Bal középső fiók: GEEC Magok
2. Magok 835 (Alma Cseresznye Narancs) – Komód felső fiók: 4db kártya (Pók) Kulcs
3. Kulcs a könyvespolc alsó fiókja – DDAY és a nagyobbik tárcsa
4. Színek 273 (Sárga Zöld Barna) – Komód alsó fiók – PHRR 4db kártya (random pakk)
5. Komód középső fiók nyitva – TO
6. Könyvespolcon nincs elzárva – I I
7. Könyvespolcon Álkönyv – 1 db kártya (Mongúz), mágnestábla rejtvénye
8. Nincs elzárva csak elrejtve
   a. Kártyák közül
      i. Irine Adler (Asztalhol a lámpának támasztva)
      ii. Pipa (dohányzó asztal közepébe)
      iii. Whiskey (Komód tetején lévő gyertyatartónak döntve)
   b. tárcsás segítség a hegedűtok első zsebében
9. Jobb alsó fiók nincs elzárva – Kisebb tárcsa
10. Megjelölt kotta 636 (soronként 6 3 6 db tá hang van) hegedűtok – 4db kártya (Tea)
11. Mágnestábla bal alsó lakása (Briany Lodge) Irine Adler, Pók, Tea, Tubák – Bal felső fiók: BULL Prizma
12. Prizma segítségével olvasható a Tárcsás segítség – „E" betű
13. N O R B U R Y az asztalba – Jobb felső fiók: Kijutás kulcsa


PHRR
TO
DDAY
BULL
GEEC
HNSS Hotel
LABIRINTUS