A Mouse-Tracking Bandit Experiment on Meaningful Learning in Weighted Voting

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March 16, 2022 at ISER Osaka U.
AP-ESA Conference 2022

Suppose that you were a subject.

choice stage (30 sec.); no choice within 30 seconds $\rightarrow$ zero point.
Each number in red can be viewed by a mouse-click.

Round 1 out of 60 remaining time 16

Choose one of two committees. The quota is 14 in both committees.
The committee you chose allocates 120 points among four members.
Click on Choice 1 button or Choice 2 button within 30 seconds.

Choice 1	member	YOU	Player 2	Player 3	Player 4
	votes	V1	V2	V3	V4

Choice 2	member	YOU	Player 2	Player 3	Player 4
	votes	W1	W2	W3	W4

Figure: Choice stage.

feedback stage 1 (30 sec.); OK button → feedback stage 2. Each number in red can be viewed by a mouse-click.

Round 1 out of 60 remaining time 23

Click on OK button within 30 seconds after seeing the following information.
You chose the following committee.

Choice 1	member	YOU	Player 2	Player 3	Player 4
	votes	X1	X2	X3	X4

The committee decided to allocate 120 points in this time as follows.

member	YOU	Player 2	Player 3	Player 4
Points	p1	p2	p3	p4

OK

Figure: Feedback stage 1.

feedback stage 2 (30 sec.); OK button → next round. Each number in red can be viewed by a mouse-click.

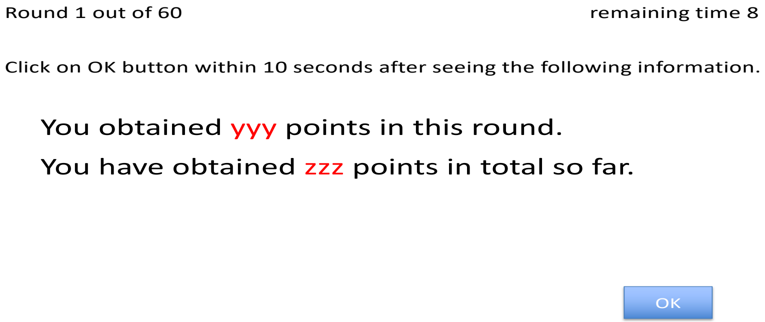

Figure: Feedback stage 2.

- Answer 60 binary choice problems (60 rounds).
  When you finish 60 rounds, you are asked to wait until the others finish.
  ($\rightarrow$ Questionnaire and Raven test)
- 1 point = 1 JPY (about 115 JPY/ USD, currently), added to the payment for participation (1000 JPY)

1. Introduction: Research Question

- **Question**: What information did subjects view, when they could (not) "meaningfully" learn the latent feature of weighted voting?
  - Felsenthal and Machover (1998): It would be difficult (for people) to see the underlying relationship between the actual voting powers and the nominal voting weights.
  - Gelman et al. (2004): Empirical voting powers are different from the theoretical predictions (Shapley-Schubik, 1954; Banzhaf, 1965).

Why?: We should use weighted voting better, because it is a popular collective decision-making system.

1. Introduction: How to answer?

When people generalize what they have learned in a situation to a similar but different one, this higher order concept of learning is called meaningful learning (Rick and Weber, 2010).

- 2-armed bandit experiment: Subjects choose one of two weighted voting games repeatedly. Payoffs are determined stochastically according to a payoff-generating function that is hidden from subjects.
  ⋯ Guerci et al. (2014): weighted voting games were played.
- Guerci et al. (2017) could **not observe meaningful learning** by subjects who received immediate feedback information on their current payoffs.
  - **Withholding feedback information induced meaningful learning** (introspective thinking). Did the subjects get confused by the feedback information?
- ⇒ mouse-tracking to capture what information subjects view on their monitor

1. Introduction: Main Result (first-cut)

The feedback Information about cumulative payoffs promoted meaningful learning, whereas the information on current payoffs did not, or even hindered it.

- This result may explain the reason why meaningful learning was not observed by Guerci et al. (2017).

2. Experimental Design

- Subjects choose one of two weighted voting games.
  - $[q; v_1, v_2, v_3, v_4]$; q is the quota, v_i is the voting weight.
  - Each subject acts as Member 1, who has v_1.
- clearly informed that the other three members are all fictitious.
- one binary choice problem (Problem) for the first 40 rounds, and a similar but different one in the following 20 rounds;
- four sequences: A $\rightarrow$ B, B $\rightarrow$ A, C $\rightarrow$ D, D $\rightarrow$C
- payoff generating function: based on Deagan-Packel index e.g., Problem A, Choice 1 $\rightarrow$ 40 point with Prob=2/3,
  0 point with Prob=1/3
  - The correct answer is Choice 2.

Table: Binary choice problems and expected payoffs for Member 1

Problem	Choice 1	(expected payoff)	Choice 2	(expected payoff)
A	$[14; \mathbf{5}, 3, 7, 7]$	$(120 \times 2/3 \times 1/3)$	$[14; \mathbf{5}, 4, 6, 7]$	$(120 \times 3/4 \times 1/3)$
B	$[6; \mathbf{1}, 2, 3, 4]$	$(120 \times 1/3 \times 1/3)$	$[6; \mathbf{1}, 1, 4, 4]$	$(120 \times 2/3 \times 1/3)$
C	$[14; \mathbf{3}, 5, 6, 8]$	$(120 \times 2/3 \times 1/3)$	$[14; \mathbf{3}, 6, 6, 7]$	$(120 \times 3/4 \times 1/3)$
D	$[9; \mathbf{1}, 3, 5, 6]$	$(120 \times 1/3 \times 1/3)$	$[9; \mathbf{1}, 2, 6, 6]$	$(120 \times 2/3 \times 1/3)$

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Figure: Feedback stage 1.

feedback stage 2 (30 sec.); OK button → next round. Each number in red can be viewed by a mouse-click.

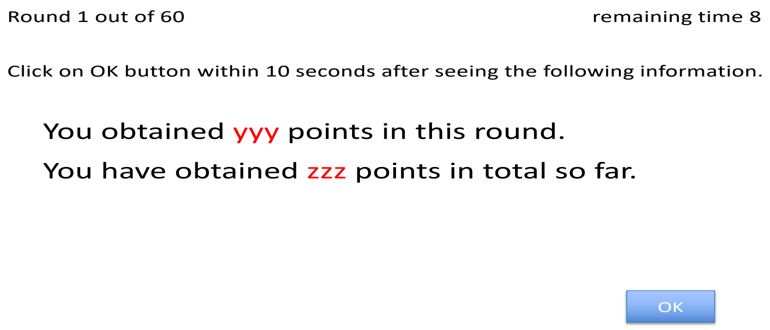

Figure: Feedback stage 2.

- Subjects answer 60 binary choice problems.
  $\rightarrow$ a message that asks them to wait until the others finish
  ($\rightarrow$ Questionnaire and Raven test)
- 1 point = 1 JPY, added to the payment for participation (1000 JPY)

3. Analysis: Session Details

- December 17 in 2014 to January 17 in 2017
- at the University of Tsukuba
- undergraduate students who do not know voting indices
- 40 subjects for each sequence (160 subjects in total)
- the average amount paid as a reward was 2507 JPY

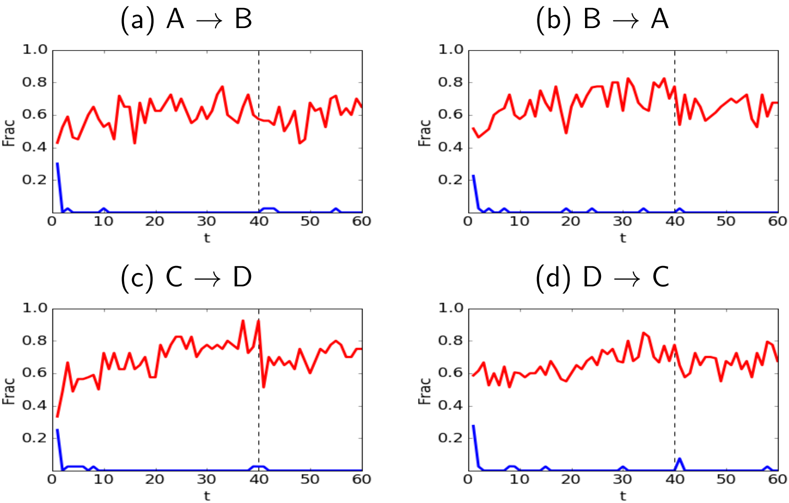

Figure: RED: fraction of subjects who chose the correct answer among those who made choices before the time limit. BLUE: fraction of those who failed to make their choice before the time limit.

- FR^i_k: the relative frequency of rounds in which subject i chose the correct answer within the k-th block of 5 consecutive rounds.
- The change in the relative frequencies that subject i chose the correct answer between the l-th block and the m-th block is defined as

$$\Delta\mathrm{FR}^i_{l,m} = \mathrm{FR}^i_l - \mathrm{FR}^i_m,$$

  where $l > m$.
- $\Delta\mathrm{FR}_{l,m}$ (FR_l): a vector the i-th component of which is $\Delta\mathrm{FR}^i_{l,m}$ (FR^i_l).
  - When the elements of FR_l are, on average, significantly larger than those of FR_m, we write this as $\Delta\mathrm{FR}_{l,m} > 0$.

3. Results: Aggregate Data

Definitions: For each binary choice problem, we consider that subjects learned the "correct" answers if $\Delta \mathrm{FR}_{8,1} > 0$ was statistically confirmed and that those who learned in the binary choice problem meaningfully learned the "underlying structure" of weighted voting games if $\Delta \mathrm{FR}_{9,1} > 0$ in the same binary choice problem was statistically confirmed.

Result 1: For all binary choice problems, the subjects learned the correct answer.

Result 2: For all binary choice problems except Problem B, the subjects meaningfully learned the underlying structure of weighted voting.

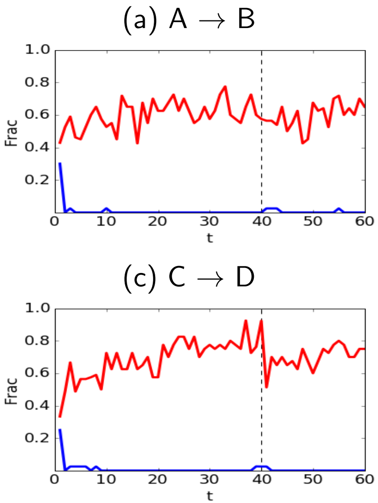

Figure: RED: fraction of subjects who chose the correct answer among those who made choices before the time limit. BLUE: fraction of those who failed to make their choice before the time limit.

	Problem A	Problem B	Problem C	Problem D
$\Delta\mathrm{FR}_{2,1}$	0.0415	**0.0086**	**0.0396**	0.6943
$\Delta\mathrm{FR}_{8,1}$	**0.0143**	<**0.0001**	<**0.0001**	<**0.0001**
$\Delta\mathrm{FR}_{9,1}$	**0.0147**	0.2498	<**0.0001**	**0.0230**

Table: P-values for the two-sided signed-rank test (normalized). The null hypotheses are $\Delta\mathrm{FR}_{2,1} = 0$, $\Delta\mathrm{FR}_{8,1} = 0$, and $\Delta\mathrm{FR}_{9,1} = 0$, respectively

- Guerci et al. (2017) could not observe subjects' learning in Problems A and D. Ogawa et al. (2021) reconfirmed a similar result at four different experimental sites.
- This striking difference from the previous results provokes a question on what information individual subjects viewed for their choice in this experiment.
  - An auxiliary experiment was conducted at Kansai University: "Cumulative payoffs" are shown to the subjects' monitors as well as their current payoffs.

3. Results: Individual Data

- two groups of subjects $G_0^{91}(s)$ and $G_1^{91}(s)$ for binary choice problem $s = A, B, C, D$: $\Delta\mathrm{FR}^i_{9,1} = \mathrm{FR}^i_9 - \mathrm{FR}^i_1 > 0$ or not
- canonical discriminant analysis: the first 40 periods to identify important variables that had a large effect on the classification of the two groups.
  - Box's M test on variance-covariance matrices $\rightarrow$ Mahalanobis distance was applied to identify the discriminant function

variable	
A_count:	numbers of views of A; $A = v_r, w_r, x_r, p_r$ $(r = 1, 2, 3, 4)$, yyy, zzz
A_time:	cumulative time for viewing A
decision_time:	time spent for the final decision in the choice stage
A_decision_time:	relative length of time spent for viewing A up to the final decision
main2_ok:	time spent in feedback stage 1
main3_ok:	time spent in feedback stage 2
no_info:	dummy variable that takes a value of 1 if the individual subject views $v_1, \ldots, v_4$ or $w_1, \ldots, w_4$ even once; otherwise, 0
judgment:	dummy variable that takes a value of 1 if $\Delta\mathrm{FR}^i_{8,1} > 0$; otherwise, 0
judgment2:	dummy variable that takes a value of 1 if $\Delta\mathrm{FR}^i_{9,1} > 0$; otherwise, 0

Table: Major variables.

3. Results: Individual Data

Definition: For each sequence of binary choice problems, we considered that subject i learned the "correct" answers if $\Delta\mathrm{FR}^{i}_{8,1} > 0$ and that those who learned in a binary choice problem meaningfully learned the "underlying structure" of weighted voting games if $\Delta\mathrm{FR}^{i}_{9,1} > 0$ in another binary choice problem in the sequence.

- the numbers of subjects who succeeded in learning (meaningful learning) were 20, 30, 32, and 27 (14, 13, 19, 17), respectively, under the following definitions.
- For every binary choice problem $s = A, B, C, D$, we could reject the null hypothesis of no difference between $G_0^{81}(s)$ and $G_1^{81}(s)$ (between $G_0^{91}(s)$ and $G_1^{91}(s)$) for independent variables, because Wilks' lambda < 0.001.

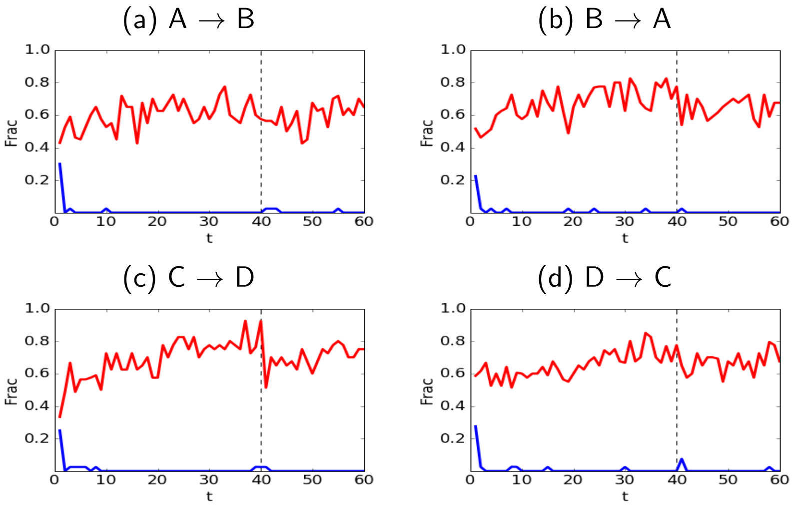

Figure: RED: fraction of subjects who chose the correct answer among those who made choices before the time limit. BLUE: fraction of those who failed to make their choice before the time limit.

A	**zzz_count**	*p1_time*	*v4decision_time*	**yyy_count**	*p3_time*
	0.678	0.627	-0.486	-0.484	-0.378

B	*decision_time*	*x1_decision_time*	*x1_count*	**zzz_count**	**yyy_count**
	-0.827	-0.552	0.521	0.506	0.241

C	*x1_count*	*x3_count*	**yyy_time**	*w4_time*	*v3_time*
	-1.359	1.040	-0.549	0.543	0.473

D	*p4_time*	**zzz_count**	*p1_time*	*no_info*	**yyy_count**
	0.749	0.479	0.315	-0.298	-0.142

Table: Standardized coefficients in the canonical discriminant functions: the four largest absolute values observed in the first 40 rounds in the discriminant function that separated well $G_0^{91}(s)$ and $G_1^{91}(s)$ for binary choice problem $s = A, B, C, D$.

Result 3:
(1) In the first 40 periods of the sequence of binary choice problems A$\rightarrow$B and D$\rightarrow$ C, subjects who succeeded in meaningful learning viewed their own cumulative payoffs more frequently than their own current payoffs, whereas those who failed in meaningful learning viewed the current payoffs remarkably frequently.

(2) In the sequence of B$\rightarrow$A, subjects who succeeded in meaningful learning also viewed their cumulative payoffs more frequently than their current payoffs in the first 40 rounds.

(3) In the sequence of C$\rightarrow$D, subjects who failed in meaningful learning spent a long time for viewing their current payoffs in the first 40 rounds.

In summary, the information on subjects' cumulative payoffs promoted meaningful learning, whereas the information on their own current payoffs did not, or even hindered it.

- This result may explain the reason why meaningful learning was not observed by Guerci et al. (2017).
  - Watanabe (2022): (1) reconfirmation of meaningful learning without any feedback information (correct answers were reversed in the first 40 rounds and the following 20 periods) (2) immediate feedback information (current payoffs) $\rightarrow$ win-stay-lose-shift (WSLS) strategy (Nowak and Sigmund, 1993) in aggregate data (5 consecutive rounds)

4. Final Remarks

- WSLS in individual data (20 consecutive rounds)
- Raven test?

external validity, internal validity
replicability, robustness

- results observed by Guerci et al. (2017)
  - replicability and external validity: Ogawa et al. (2021) ... (meaningful) learning without WSLS+Raven score
  - robustness: Watanabe (2022) ... meaningful "introspective thinking" with correct answers being reversed.

Table: Raven scores of general public: April 2015-March 2018

test site	# of subj.	mean	std. dev.	min	max
EEL at Kansai U	1,057	7.986	3.326	0	16

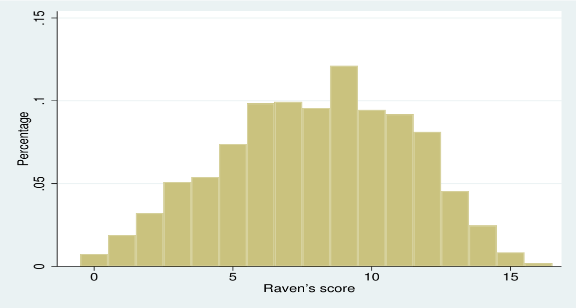

Figure: Histogram of Raven scores of non-student general public