Investigate How People Understand Diagrams In Order To Construct A Kinematic Representation of A Physical System By Recording Eye Movement

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Introduction

- Inner kinematic representation is defined as a coherent mental model that learners construct over time from external representations through cognitive activities (Hegarty, Kriz, & Cate, 2003); it involves combining temporal and spatial information of an external event. However, how and when this occurs has been unclear.
- The purpose of this study was to investigate how people understand diagrams in order to learn about a physical system by recording eye movement and comprehension tests. Specifically, we want to know if readers could construct kinematic representations of a physical system by reading diagrams with arrows to guide attention.

Method

Participant

- Forty-six undergraduate students from the National Taiwan Normal University volunteered to participate for a monetary reward.
- They majored in education, management, arts, and social science. We excluded students who majored in science or engineering; therefore, the participants were expected to have minimal background knowledge in science and engineering.
- All participants had normal or corrected-to-normal vision.

Apparatus

- Eye movements were recorded by an Eyelink 1000 with a sampling rate of 1000HZ. A chin rest was used to minimize head movement.
- Texts were displayed on the 24-inch LCD monitor. The screen resolution was set to 1920*1200 pixels. The distance between the monitor and participants was 60 cm.
- The reading material covered 46° (horizontal) × 30° (vertical) of visual angle on the screen.

Materials

- Two diagrams describing how a flushing cistern works, modified from Hegarty et al. (2003), were used as experimental materials as Figure1.
- There were two diagrams, describing the "outlet process" and "inlet process" of the flushing cistern, respectively. The outlet process flushes water out of the tank and into the bowl of the flushing cistern. The inlet process pumps fresh water into the flushing cistern tank from the water inlet pipe.
- Our study manipulated whether numbered arrows were presented on the two diagrams. The arrows in the arrow version have numbers to indicate each sequential step of flushing cistern operation. Except for the presence or absence of arrows, there were no difference in the content and arrangement of the diagrams.

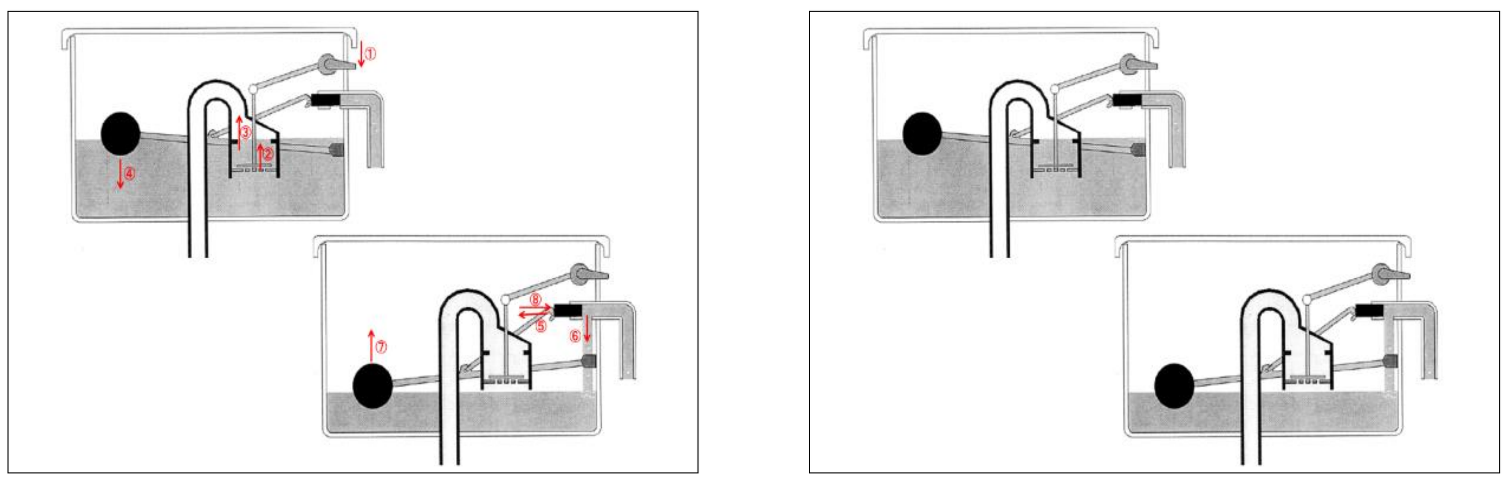

Figure 1. The two-stage diagram of a flushing cistern in this study. The left diagrams were arrow version and the right diagrams were non-arrow version.

Procedure

- At the beginning, all participants studied and remembered the 10 flushing cistern component labels for 2 minutes. Then the formal learning phase began. The two flushing cistern diagrams were shown on the screen, and participants were instructed to spend approximately 5 minutes reading the diagrams to learn how the flushing cistern operates for a subsequent comprehension test.
- After participants indicated that they understood the procedure, 12-point calibration and validation of eye-movements were conducted.
- It took approximately 20–30 minutes for each participant to complete the experimental procedure.

Results

Learning outcomes

- Table 1 showed the arrow group had significantly higher accuracy on total steps, outlet-process steps, and inlet-process steps than the non-arrow group.
- In addition, the arrow group only had significantly fewer continuous relation errors than the non-arrow group.

Table 1. Accuracy and the error number of the step-by-step test for arrow group and non-arrow group

	Arrow group		Non-arrow group		*t*-value
	M	*SD*	*M*	*SD*	
Accuracy (%)					
Outlet-process steps	21	(10)	8	(8)	4.44***
Inlet-process steps	62	(20)	28	(23)	4.95***
Total steps	42	(13)	18	(13)	5.90***
Error number					
Sequential relation	0.10	(0.31)	0.10	(0.31)	0.00
Direction alter	0.20	(0.52)	0.10	(0.31)	0.74
Continuous relation	0.60	(0.94)	1.35	(1.31)	–2.08*
All error number	0.90	(1.15)	1.55	(1.28)	–1.53
Response time (minute)	6.25	(1.79)	6.60	(2.14)	–0.56

***$p < .05$ ***$p < .001$**

Eye movements analysis

- Table 2 showed the arrow group had shorter mean saccade lengths on the diagrams and had longer gaze durations toward the first diagram than the non-arrow group. As for the non-arrow group, the strategy they seemed to use was comparing the status between the two diagrams. Therefore, there were more saccades between the two diagrams for the non-arrow group than for the arrow group.

Table 2. Means and standard deviations on eye-movement measures for two groups while analyzed the whole diagram and the two-stage diagrams

	Arrow group		Non-arrow group		*t*-value
	M	*SD*	*M*	*SD*	
The whole diagram					
Total fixation duration (sec)	181.82	(89.19)	158.73	(81.10)	0.92
Mean saccade length (visual angle)	2.92	(0.49)	3.69	(0.71)	–3.61***
The two-stage diagrams					
Outlet-process diagram					
Total fixation duration (sec)	81.52	(38.23)	74.99	(43.81)	0.50
Proportion of fixations on diagram	0.56	(0.13)	0.57	(0.11)	–0.22
The number of gaze duration	53.70	(39.79)	22.00	(31.45)	2.80**
Gaze durations (sec)	15.36	(9.70)	6.64	(10.80)	2.68*
Mean saccade length (visual angle)	2.92	(0.48)	3.14	(0.47)	–1.46
Number of saccades from inlet to outlet	15.55	(9.40)	23.70	(14.73)	–2.09*
Inlet-process diagram					
Total fixation duration (sec)	67.49	(43.00)	59.14	(38.47)	0.65
Proportion of fixations on diagram	0.44	(0.13)	0.43	(0.11)	0.24
The number of gaze duration	8.85	(7.80)	3.60	(2.64)	2.86**
Gaze durations (sec)	2.21	(2.41)	0.88	(0.73)	2.35*
Mean saccade length (visual angle)	3.20	(0.39)	3.31	(0.51)	–0.76
Number of saccades from outlet to inlet	14.90	(9.39)	24.00	(15.70)	–2.23*

***$p < .05$ **$p < .01$ ***$p < .001$**

Conclusions

- Both groups engaged in different cognitive processes during kinematic representation construction. Participants in the arrow group were capable of constructing kinematic representations to some extent, but participants in the non-arrow group failed.
- Numbered arrows on diagrams not only provide perceptual information but also facilitate cognitive processing.
- Results of the comprehension test suggest that a well-designed diagram with numbered arrows is beneficial for the formation of a kinematic representation of a mechanical system in low-knowledge readers and, in particular, for learning continuous relationships between components.

Acknowledgment

This study is supported by the grant NSC101-2511-S-003-015 from the National Science Council in Taiwan