Student's Adaptive Choice of Instruction Format

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Abstract

A spatially distributed instruction format (i.e., when information sources are presented side-by-side) has been found to be generally beneficial for learning statistics (Jang, Schunn, & Nokes, 2011). In a follow-up classroom study, we examined whether students generally selected the better format (i.e., faster problem solving with better understanding of materials; distributed format in this study) when given the choice and whether individual differences affect students' instruction format preferences. Students were found to prefer the instruction format that matches to their ability (an adaptive choice): Students with high mental rotation and verbal learning ability preferred the spatially stacked format of instruction to a distributed format.

Keywords: Cognitive load theory; split-attention effect; instruction design; individual differences.

Introduction

Spatial arrangement of information has been found to be important for learning, as it affects the amount of extraneous load that students may experience. According to cognitive load theory (Sweller, van Merriënboer, & Paas, 1998; van Merriënboer & Sweller, 2005), three types of cognitive load consume a single limited working memory capacity. Two of them are beneficial for learning: Intrinsic load is required for learning itself (e.g., information processing, understanding, schema construction); thus it reflects the inherent difficulty of a given task. Germane load is caused when learners actively engage in learning (e.g., filling in blanks of worked examples). In contrast, extraneous load is harmful for learning because it imposes an unnecessary load that is not related to learning (e.g., split-attention effect: learners' attention is split across separately presented information pieces that are, in fact, meaningful when integrated). Extraneous load can be quite detrimental to learning, especially for integrative tasks (i.e., when dispersed learning components are so closely related to each other as to be meaningful only when taken together: inherently high intrinsic load). For example, the normal benefit of worked examples (i.e., studying a fully solved problem rather than actively solving one) can be wasted due to a small increase of extraneous load. It has been repeatedly found that learners no longer benefit from worked examples when the text and diagrams are presented in a separated format (Tarmizi & Sweller, 1988; Ward & Sweller, 1990). Thus, it is recommended to design instructions in an integrated format.

Integrated formats are, however, impractical for complex tasks that require integration across many sources of information (Wickens & Carswell, 1995). As the volume of information to integrate increases, separated but spatially distributed format of display (i.e., when information sources are presented side-by-side) can be a practically and theoretically robust alternative (Jang & Schunn, under review; Jang, et al., 2011; Wiley, 2001). We have found that spatially distributed displays shorten problem-solving time and facilitate learning, when compared to spatially stacked displays (i.e., when information sources are sitting on top of one another with only the top source fully visible). In a series of experiments involving learning of statistics, students were provided with instructions either in a spatially distributed or a spatially stacked format (Jang, et al., 2011). Students who worked with the distributed format of instruction finished a t-test analysis significantly faster without any loss of accuracy, and scored higher on a post-test than those who had the same instruction in a stacked format. Moreover, students in the stacked format condition reported higher level of cognitive load than those in the distributed condition.

Although the finding is consistent with cognitive load theory in that it shows the continuum of split-attention effect (i.e., as the degrees of separation increase, the amount of extraneous load grows along integrated displays < distributed displays < stacked displays), a more important theoretical question remains unsolved: What causes the extra cognitive load in the stacked display? A recent eye-tracking study suggested that problem solvers may shift to an information memorization strategy in stacked conditions, and this memorization time could account for the stacked display time disadvantage (Jang, Trickett, Schunn, & Trafton, under review). Participants in the stacked display condition fixated significantly longer on information pieces on each page throughout an integrative problem-solving task than those who solved the same problem using the distributed display, presumably as a micro-strategy to bypass the relatively higher information access cost in the stacked display. That is, the stacked display presumably produces a high information access cost situation because information is a page-turn away, compared to the cost of an eye/head turn away in the distributed display. Consequently, problem solvers chose to memorize information rather than repeatedly turn pages to look for information (Gray & Fu, 2004). When the cost of accessing external information increases, people tend to memorize information to make it readily accessible *in the head* (i.e., memorization strategy; stacked display). In contrast, when information access cost is low, people do not bother to memorize information and instead rely on external/ *in the world* information (i.e., perceptual-motor strategy; distributed display).

In terms of performance accuracy, the memory strategy selection can be construed as an adaptive choice balancing accuracy and effort. Information *in the world* is accurate but that *in the head* may not be. For example, participants made more errors in a given task when they adopted the memorization strategy, but with a reduction in task time (Gray & Fu, 2004).

Even though people on average may seem to adopt one strategy for a given situation, individuals with different cognitive ability may react differently to the demands of the same situation. Then, what if we give them a chance to choose a format of instruction for themselves? In the strategy choice literature, problem solvers are thought to select strategies that reduce effort and increase the probability of solving the given problem (Gray & Fu, 2004; Kerkman & Siegler, 1993; Lovett & Anderson, 1996). When there are individual differences in strategy preference, this can be explained in one of three different ways: 1) some people value the problem solving goal more, and thus are willing to use more effortful and successful strategies to achieve the goal; 2) some people have less experience with some of the strategies and have not yet figured out which strategies are the best balance of likely success and minimal effort; and 3) through different overall skill levels with each strategy, different people will have different strategies that best balance likely success and minimal effort. So when we see problem solvers making apparently non-adaptive choices, we ask: do they simply not care, do they not know, or is their choice actually adaptive for them?

In the current study, we gave students free choice between two formats of instruction and examined how individual differences interact with instruction format choice. We measured mental rotation ability given the visual-spatial element to the statistical thinking learning topic being examined as well as the experimental manipulation itself (distributed vs. stacked format). Also, individual learning style (self-report questionnaire) was measured as an index of perceived strength of cognitive abilities in the two general cognitive ability dimensions (verbal and visual), allowing for some teasing apart of the effects of actual ability versus self-perceived ability/style.

The better choice in this setting (based our prior work with exactly these materials in exactly this class context) is to choose distributed instructions as they will produce less cognitive load on memory regardless of students' cognitive ability. But an adaptive choice can also be made depending on each individual's cognitive ability, which leads to some interesting ambiguities regarding what to predict. Which individuals will select the distributed vs. stacked formats? Those with lower spatial skill may be in more need of the cognitive supports of the distributed format, while those with higher spatial skill are more able to memorize content from prior pages. Alternatively, those with lower spatial skill may have less practice with spatially distributed information. Further, those who are visualizers may prefer more spatially rich environments as afforded by the distributed format.

Method

Participants

Participants consisted of 50 undergraduates (39 women) enrolled across three lab sections of an introductory cognitive psychology course at the University of Pittsburgh. All students had previously completed prerequisite courses in psychology research methods and introductory statistics.

Design

The experiment consisted of four phases—background instruction, practice, testing, and individual differences. Students were allowed to freely choose one of two formats: distributed format instructions or stacked format instructions during the practice phase. All four phases were implemented as normally scheduled lab activities. The background phase covered two consecutive labs one week apart (1.5 hours each, 3 hours in total), the practice and testing phase occurred in the third lab, and the individual differences were measured five weeks later. During this period, students learned about and practiced how to analyze independent two-sample data using common data organization and statistic tools (i.e., Excel and SPSS).

Materials

The Background Phase During the background phase, detailed handouts were provided for four main steps in a basic data analysis procedure relevant to basic cognitive psychology lab studies: (1) organize the data (e.g., how to count the number of males and females using Excel, and how to calculate the derived dependent variable), (2) create a pivot table (e.g., how to calculate means, standard deviations, and Ns using the pivot table function in Excel), (3) create a graph (e.g., how to calculate standard errors and create a graph with standard error bars in Excel), and (4) run a t-test (e.g., how to run an independent samples t-test in SPSS and interpret outputs). Step-by-step text instructions and corresponding screen shots that matched exactly to the practice data were provided in the form of stapled letter-size documents. Two practice datasets were given to students; one for the in-class learning activity and the other for homework. The data sets shared a common structure (i.e., no difference in terms of running analyses) but their cover stories and numbers were different for practice purposes.

The Practice Phase During the practice phase, students were asked to freely choose the instruction format (i.e., distributed or stacked format) according to their preferences. Given that students had practiced the same analysis twice before, this time the instructions were less detailed than those provided in the background phase. However, core information (e.g., complex equations and high-level instructions) was kept intact. For the distributed format condition, instructional text and accompanying screenshots were presented on an 11x17 paper, with four sources of information laid side-by-side on a single-side of the paper (i.e., four separate panels of information: see Figure 1). For the stacked format condition, the distributed format was cut into four pieces (one for each of the four steps: see Figure 2) and stapled. Exactly these two formats with exactly this content were used in the previous study that found a large overall performance and learning advantage of distributed instructional format (Jang, et al., 2011).

To measure task time, accuracy, and cognitive load during the practice phase, a four-page task worksheet was provided, which asked students to record start and end times of each step, to report a few requested results, and to rate the degree of perceived cognitive load on a 9-point scale.

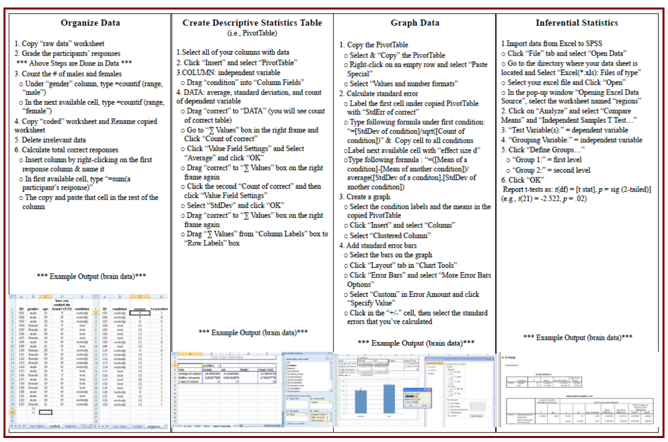

Figure 1. Distributed format of instruction.

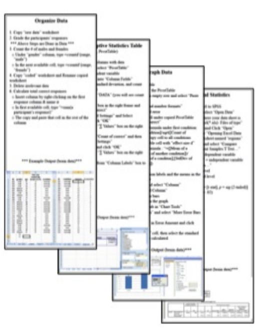

Figure 2. Stacked format of instruction.

The Testing Phase During the testing phase, to examine why students chose one format over the other, a brief survey was implemented at the beginning of the test booklet, consisting of one open-ended question asking for reasons for the choice. To measure overall learning outcomes, a 26-item closed-book test (21 multiple choice and 5 short answer questions; Cronbach's alpha = .57) was used, which covered various types of questions targeting factual, conceptual, and integrative knowledge. The test items were developed to closely match the broad instructional goals of this unit. The modest overall alpha reflects the diversity of concepts that were being tested. Previously, distributed vs. stacked instruction conditions produced a difference in learning outcomes on this test.

Individual Differences To examine the relationships between individual differences and instruction format preference, two tests measuring individual differences were implemented: a mental rotation test (Peters et al., 1995; 24 items, Cronbach's Alpha=.87) and a verbal and visual learning style questionnaire (Mendelson & Thorson, 2004; 20 items, Cronbach's Alpha=.67).

Procedure

Students worked individually at computer workstations in the lab for the background instruction and practice phases. For the background phase, students learned how to analyze data from a one-factor study. They learned four main steps of data analysis (i.e., organize data, create a pivot table, draw a graph, and run a t-test), two per lab. The first three steps were done in Excel and the last step was done in SPSS. Detailed handouts for each step were provided and lab instructors walked through each step with students during the lab. Homework was assigned to allow students to begin to practice each step on their own. Students could ask questions or request help from instructors at any time during the background phase.

For the practice phase, students selected the format of instruction that they preferred to use: either the distributed or stacked version. Students were asked to analyze new data from a one-factor study, but within a maximum time of 40 minutes and on their own. They were allowed to use only the less detailed handout in the format that they chose to use that day. While completing this data analysis task, they filled out a task worksheet. Students who finished the task early turned in handouts and task worksheets, and then they were allowed to quietly engage in any other activity while the other students completed the task. After the 40 minutes of data analysis activity, all students filled out the format preference survey for 5 minutes and took the overall learning test for 25 minutes (the testing phase).

Five weeks later, students were given a booklet measuring their mental rotation ability and cognitive learning style—7 and 5 minutes were given to each test, respectively.

Results

Out of 50 students, 16 chose distributed and 34 chose stacked format of instruction, a surprising overall ratio given that the distributed format had previously produced more efficient problem solving and greater learning outcomes.

Table 1. Correlations between the measures of performance and individual differences with format choice (distributed=1, stacked=0).

Dependent Measures	Format choice	Task time	Task accuracy	Cognitive load	Test score	Mental rotation	Verbalizer	Visualizer
Format choice	-	.06 N=48	-.08 N=49	.09 N=49	-.29* N=49	-.39** N=43	-.34* N=43	-.10 N=43
Task time		-	-.37* N=48	.65** N=48	-.27 N=47	-.14 N=41	-.16 N=41	-.06 N=41
Task accuracy			-	-.29* N=49	.34* N=48	.16 N=42	-.07 N=42	.12 N=42
Cognitive load				-	-.14 N=48	-.39* N=42	-.33* N=42	-.31 N=42
Test score					-	.36* N=43	.35* N=43	.17 N=43
Mental rotation						-	.09 N=43	.23 N=43
Verbalizer							-	.09 N=43

Note. *p < .05. **p < .01.

The size of N varied across the analyses as some students missed a lab during the four weeks of experimentation.

Reason for choice (Self-report)

Open responses from the format preference survey (distributed N=16 vs. stacked N=34), which was collected at the beginning of the test phase, were categorized as follows (multiple categories possible per student given the sometimes extended written responses). Students who preferred the distributed format reported the benefit of having everything in a single view: Easy to see everything (63%), No need to turn a page (56%), Easy to follow steps (25%), Easy regression to previously visited instruction (13%).

By contrast, students who preferred the stacked format reported the benefits of easy manipulation (size issue) and less distraction from overflowing information: Small-size instruction considering limited space of lab desks (59%), Less distracting so as to do a step at a time (50%), Easy to keep track (9%), Easy regression (3%).

Table 2. Means and SDs for performance and individual differences measures as a function of instruction format.

	Distributed		Stacked	
	M	*SD*	*M*	*SD*
Task time (min)	25.3	4.6	26.4	6.5
Task accuracy (%)	91.8	13.5	92.6	8.5
Cognitive load (9)	3.1	0.8	3.3	1.2
Test score (%)	66.0	8.4	72.7	12.7
Mental rotation (24)	6.4	4.5	10.5	4.5
Verbalizer (%)	61.3	6.8	68.1	9.5
Visualizer (%)	73.7	13.1	76.1	9.9

Performance

From an adaptive strategy selection framework, we expect that performance differences across representational formats will disappear when individuals are given free choice between formats because each individual will select the more adaptive choice for him or herself.

A MANOVA (listwise deletion: distributed, N=13 vs. stacked, N=34) was conducted examining the effect of selected format on the dependent measures obtained from the practice and testing phase: task time, task accuracy, task cognitive load, and test score. Consistent with our expectation, no overall significant effect was found between the two self-selected formats, Wilks' $\Lambda=0.91$, $F(4,42)=1.02$, $p=.41$. Univariate tests showed no difference as well[1]: task time, $F(1,45)=.30$, $p=.59$; task accuracy, $F(1,45)=.07$, $p=.80$; task cognitive load, $F(1,45)=.19$, $p=.66$. Test score was marginally significant, $F(1,45)=3.04$, $p=.09$. Means and SDs are presented in Table 2.

Individual differences: better vs. adaptive choice

A MANOVA (listwise deletion: distributed N=13 vs. stacked N=30) was conducted, examining the effect of format choice on individual differences measures: mental rotation test score and visual/verbal learning style scores. Significant differences were found between the two formats, Wilks' $\Lambda=.75$, $F(3,39)=4.24$, $p=.01$. Univariate tests indicated significant differences for mental rotation score and verbal-learning style score, but not visual-learning style score[2]: mental rotation test, $F(1,41)=7.53$, $p=.01$, Cohen's

[1] Levene's tests: task time $F(1,45)=1.32$, $p=.26$; task accuracy $F(1,45)=.99$, $p=.32$; task cognitive load $F(1,45)=2.52$, $p=.12$; test score $F(1,45)=2.35$, $p=.13$.

[2] Levene's tests: mental rotation test $F(1,41)=.41$, $p=.53$; learning style verbal $F(1,41)=1.26$, $p=.27$; learning style visual $F(1,41)=.69$, $p=.41$.

d=0.91; verbal-learning style, $F(1,41)=5.32$, $p=.03$, Cohen's *d*=0.83; visual-learning style, $F(1,41)=.44$, $p=.51$. Means and SDs are presented in Table 2.

In summary, students who selected the stacked format of instruction had significantly higher mental rotation scores and verbalizer ratings than students who selected the distributed format. Note the surprising combination of higher spatial ability with higher verbalizer style, rather than with visualizer style.

To further unpack the relationships between the measures, a correlation matrix was computed with format choice coded as 1 for distributed and 0 for stacked format. As shown in Table 1, several statistically significant correlation patterns were found. First, there was no sign of time-accuracy trade off; in fact, a negative relationship was observed between task time and task accuracy.

Second, plausible correlations were found between cognitive load, task accuracy, and test score. Students who experienced a higher cognitive load took longer to finish the task and scored lower on task accuracy. Not surprisingly, task accuracy and test score were positively correlated, which suggests that test items were well matched to the skills and knowledge required in the task.

Third, a significant negative correlation was found between format choice (distributed=1, stacked=0) and test score. Students who chose the stacked format tended to score higher in the test; however, the difference was not large enough to be statistically significant with the list-wise deletion used in the MANOVA (see results in the Performance section). Even though the format these students selected (stacked format) was not the overall better choice (distributed format), they had higher levels of learning, presumably the result of their higher individual cognitive abilities rather than their instruction format choice.

Finally, individual difference measures showed several interesting relationships with cognitive load and test score. Students who had higher mental rotation and high rated verbal learning ability (who chose the stacked format more often) reported lower perceived cognitive load and they scored better on the test. The overall results suggest that students made adaptive instruction format choices that matched to their abilities and learning styles.

Discussion

At the overall level, leaving individual differences aside, students were found to choose the stacked format of instruction more often, which is the opposite of what is known to be beneficial. This odd preference may be the result of students' general resistance to an unfamiliar format of instruction (Davis, 1993). In problem-solving settings, several studies have found that people preferred stacked displays over distributed displays even when distributed displays were readily available—e.g., two monitors were set up on desks (Jang & Schunn, under review)—or when participants were specifically instructed to use two-windowed browser design rather than a single browser design (Wiley, 2001).

Once individual differences were included in the framework, the current study showed that the seemingly odd preference for stacked display could in fact be plausible. It demonstrated that individual differences among students in terms of cognitive abilities and learning styles might significantly differentiate the extent to which a student could benefit from instructional manipulations. What might benefit some students may not necessarily do the same for other students. Depending on students' abilities, a generally recommended format of instruction may provide redundant information that could distract learners' attention, as it was found in studies comparing novice and intermediate learners in the domain of electricity (Kalyuga, Chandler, & Sweller, 1998).

More importantly, this study showed that students could adaptively select the instruction format they needed. As further examination of individual differences measures suggests, students were able to make sufficiently effective choices in instructional formats they would use for their learning. Specifically, we found that students with higher spatial ability and advanced verbal skill chose the stacked format of instruction more often than students who were less skilled in those dimensions. Presumably, the better choice for the students in our study was distributed because they were all novices in the domain of statistics, as was shown in a prior study that took place in the same setting (Jang, et al., 2011) . Even though their choice was not the generally better choice, it is interesting to see that students could choose instructional formats adaptively so that the instruction did not hinder their learning and performance, rather than selecting the opposite or on a random basis.

Also, it is interesting to observe that students' adaptive format choices were made in a compensating manner, rather than in an additive way. Although one could expect that high spatial ability students may prefer spatially rich distributed format as these choices play to their strengths, the results showed the opposite. High spatial ability students might have not bothered to use the distributed format as their cognitive ability likely could overcome the extraneous load coming from the stacked format. Further, it could be that the spatially rich format may distract and hinder learning of high spatial ability students as such students may be sensitive to spatial features.

It is also notable that verbalizers selected the stacked format more often than visualizers. According to the way the cognitive learning style test is structured, a student can be high in both; verbal and visual abilities are treated as separated dimensions that can coexist, and our data supported independence on these scales. The relationship of various variables with style may suggest an effect that is not specific to our manipulation. In general, verbal skill is essential to any learning because instructions and tests are mainly provided in text. The positive correlation between verbalizer score and test score, and the negative correlation between verbalizer rating and cognitive load could reflect the general learning component. Also, as the low non-significant correlation between visualizer rating and mental rotation score shows, visual and spatial abilities are two different constructs; while visual is more related to diagrams or pictures (e.g., a preference/ability to use diagrams to explain things), mental rotation is more related to spatial features (e.g., an ability to grasp relative spatial relationship between objects) per se. Furthermore, the instructions in this study were mainly offered in text, and diagrams were only to show an example of end state for each analysis step. Thus, it seems plausible that the visualizer score did not show a contribution as strong as mental rotation score did.

As a specific caveat of this study, the small desk space in the lab might have encouraged students to choose the stacked format as it was indicated in the format preference survey; the majority of the students who selected the stacked format mentioned the space issue. More carefully prepared experimental materials and environment may be needed to take advantage of distributed materials without these space-use problems, because statistics learning often involves manipulating many resources (e.g., instructional handouts, multiple windows showing data and statistical packages, and practice worksheets) in a small space.

For future studies, other individual factors could be tested as well. Particularly, visual and verbal working memory capacity may need to be included, as use of a memorization strategy was found to be dominant in stacked displays. It suggests that even a small increase of information access cost in the stacked display—due to spatial separation—was large enough to induce extraneous load on working memory. Supposedly, individual difference in working memory capacity could produce differential effect on learning from distributed vs. stacked formats of instruction via adaptive strategy choices. Likewise, further attention to the presentation of learning materials can prove to be a fruitful enterprise, both for building our theoretical understanding of working/spatial memory, and for helping to improve educational practice.

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