Learning Aid Use Patterns and Their Impact on Exam Performance in Online Developmental Mathematics

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ABSTRACT
Developmental mathematics is a college course aimed to remediate areas missed in high school mathematics. These courses are often offered online, which offers new opportunities to deliver content and learning aids to students. We utilize cluster analysis to identify learning aid use patterns, and then investigate their correlation to subsequent exam performance.

Keywords
Learning aids, online learning, cluster analysis

1. INTRODUCTION
Digital learning aids are often available to university students [7], and are used by novices as they solve novel problems and learn new material [5]. Indeed, most textbook publishers offer online or digital course content to instructors. We focus our research on digital learning aids because of their growing use, and research suggests that individuals who are engaged in learning seek information, such as learning aids, from online sources [2].

Digital learning aids can come in various formats, including text, videos, animations, and solution guides. Prior studies have shown that individuals use various learning aids to increase learning [e.g., 3], but it is still unknown what *combination* of learning aids impact student learning. That is, when several types of learning aids are available, do students display patterns of preferred learning aid use? To address this, we investigate the combinations of learning aids used by students, and the correlations of these combinations with student exam performance.

2. BACKGROUND
There is a great deal of prior work on how various learning aids may affect learning. For instance, it may be faster to study worked examples than to solve problems on the same skill, and studying worked examples enables faster subsequent skill application [8]. However, what is needed is a learning-analytic approach that examines the use of learning aids *in vivo*. Moreover, real-world use of learning aids reflects student preferences, habits and beliefs, distinct from so-called learning styles [6]. Because student preferences may differ and these preferences may change over time, this calls for a model of how students use learning aids. Based on sourcing theory [3], we investigate the learning aid use patterns seen in an online learning environment, and examine the correlations these patterns have on subsequent exam performance.

1. What learning aid use patterns are seen among college students in a developmental math course using online resources?

2. Do these learning aid use patterns correlate with subsequent exam performance?

3. METHODS
We used existing log data on a single course of 160 students. The subject was Developmental Mathematics, an introductory course for students who enrolled in college but lacked prerequisites for further study. We did not separate students into conditions. Demographic information was not available. No compensation was associated with the study. Instructor and students participated with the course management site as normal.

The online course management site gave instructors the ability to select assignments for their students. We captured learning aids available in our study context: animation, calculator, sample problem, textbook, and video. Each learning aid was not available for all homework problems, so the percentage of use was reported (calculated as number of learning aids used divided by number of learning aids available). These and other variables are described.

Animation: short animations of movement and graphics.

Calculator: provided through the web interface; included even though a student could use their own calculator.

Sample problem: worked example for the problem at hand with values that are different from the current problem. Each step is demonstrated and explained.

Textbook: content from the corresponding section in the textbook.

Video: distinguished from animations in that they are longer, include more explanation, and include audio.

Exam performance: performance that follows the use of learning aids; calculated as the number of problems answered correctly divided by the number of problems attempted. We do not include unanswered exam questions, because a student may know how to correctly answer questions they never see or questions they skip (e.g., by employing a test-taking strategy wherein they skip problems with the intention of returning to them later).

IRT difficulty: average for all problems on the exam across all occurrences of a problem (i.e., across all courses).

Exam number: sequence number of each exam.

Pretest Performance: the student's score on questions from the first exam covering whole numbers.

4. ANALYSIS AND RESULTS

What learning aid use patterns are seen among college students taking a developmental math course using online resources?

To investigate learning aid use combinations among college developmental math students, we develop a classification with cluster analysis [4]. We conduct our cluster analysis in three steps. First, we compile the learning aids used by each student between exams. Because we are interested in learning aid combinations regardless of when the combination appears, we look at all time periods between exams for all students. For example, if one student takes four exams, we include four learning aid use combinations, corresponding to the four time periods that the student could have used learning aids. We excluded all exams where the student completed less than ten percent of the exam questions. In total, the 160 students took 2,989 exams (average 18.68 exams), resulting in 2,989 learning aid use combinations.

Second, we clustered the learning aid usages. Hierarchical cluster analysis was selected for this analysis, because there was no theoretical reason for a priori specification of the number of combinations used by students [4]. Clustering was conducted using five methods: Ward's [10], centroid, median, between-groups linkage, and within-groups linkage.

Third, we evaluated the cluster solutions. We examined possible solutions including three to seven clusters by examining the change in agglomeration coefficients, cluster membership (i.e., excluding any solutions with very small membership), and significance of univariate F-tests [9]. Based on these analyses, the solution using Ward's method with three clusters performed best. These three clusters were significantly different ($p < 0.001$). This solution included one large cluster (n=2,351), and two smaller clusters (n=228 and n=410), which we describe next.

To better understand the clusters, we conducted post hoc comparisons of the means of each learning aid using Games-Howell test, because there are more than two clusters and equal variances are not assumed [4]. This test conducts pairwise comparisons for each learning aid across clusters, and significant differences are identified (at a predefined level, $p < 0.10$ in this exploratory study). The test sorts these means into groups, where the means of learning aid use within a group are not significantly different from others within the same group, but are significantly different from those in other groups.

Table 1. Comparison of Learning Aid Clusters

	F-values[a]		Cluster 1 Low Use		Cluster 2 Moderate Use		Cluster 3 High Use	
Animations	47.678	*	0.00%	L[b]	0.00%	L	2.00%	H
Calculators	3413.733	*	0.10%	L	24.80%	H	1.40%	M
Sample problems	3087.162	*	0.00%	L	6.50%	M	27.00 %	H
Textbook	109.529	*	0.10%	L	2.50%	H	1.30%	M
Videos	103.285	*	0.00%	L	0.00%	L	3.00%	H

[a] Significant at the $p < 0.001$ level.

[b] H, M and L indicate that the mean for the cluster was high, medium or low, respectively, based on Games-Howell Test.

Cluster 1: Low Use. This learning aid use combination represents a minimalist approach to learning aid use and exhibited significantly low levels of all learning aids investigated.

Cluster 2: Moderate Use. This learning aid use combination exhibited greater variability in learning aid use, and exhibited very traditional resources when learning.

Cluster 3: High Use. This learning aid combination exhibited the highest overall use of learning aids, with a preference for media.

We also report the distribution of learning aid combinations used by students. 13% of students do not change learning aid use combinations throughout the course (all Low). 45% of students use two learning aid use combinations during their coursework. (Approximately half utilize Low and High Use combinations, but not Moderate Use, and half utilize Low and Moderate Use combinations, but not High Use; no students use Moderate and High Use combinations without Low Use.) 42% of students use all three combinations.

Do these learning aid use patterns correlate with subsequent exam performance?

Armed with these learning aid patterns, we investigate the relationship between learning aid cluster and exam performance, and conduct a random effects generalized least squares regression analysis using cluster (recoded into dummy variables), exam number, IRT difficulty, and pre-test score as independent variables. The results indicated the predictors accounted for 30.2% of the variance in exam performance ($R^2 = .302$, $F(5,2989)=749.67$, $p = 0.00$). Exam performance was significantly influenced by IRT difficulty (ß = -1.50, $p = 0.00$), pretest score (ß = 0.17, $p = 0.001$), and cluster 3 (High Use) (ß = -0.04, $p = 0.00$); cluster 2 (Moderate Use) and test number were not significant. That is, we find that the high use learning aid combination correlates with low exam performance, just as high hint use correlates with low proficiency [1]. It is likely that students who make the most use of learning aids are weaker students, which explains their lower exam scores. The results imply that we need to separate the study of learning aid use in low-ability students from high-ability students.

5. REFERENCES

[1] Goldin, I. M., Koedinger, K. R., & Aleven, V. (2012). Learner Differences in Hint Processing. *Int Ed Data Mining Soc.*

[2] Gray, P. H., & Durcikova, A. (2006). The role of knowledge repositories in technical support environments: Speed versus learning in user performance. *J Man Info Sys*, 22(3), 159-190.

[3] Gray, P.H., & Meister, D.B. (2004) Knowledge sourcing effectiveness. *Manage Sci*, 50(6), 821–834.

[4] Hair, J.F., Black, W.C., Babin, B.J., Anderson, R.E., & Tatham, R.L. (2006). *Multivariate Data Analysis* (2nd ed.). New Jersey: Pearson Prentice Hall.

[5] Markus, M. L. (2001). Toward a theory of knowledge reuse: Types of knowledge reuse situations and factors in reuse success. *J Manage Inform Syst*, 18(1), 57-94.

[6] Pashler, H., McDaniel, M., Rohrer, D., & Bjork, R. (2008). Learning styles concepts and evidence. *Psych Science Public Interest*, 9(3), 105-119.

[7] Rowley, J. (2000). Is higher education ready for knowledge management? *Int J of Educ Manage*, 14(7), 325-333.

[8] Sweller, J., & Cooper, G. A. (1985). The use of worked examples as a substitute for problem solving in learning algebra. *Cognition Instruct*, 2(1), 59-89.

[9] Ulrich, D., & McKelvey, B. (1990). General Organizational Classification: An Empirical Test Using the United States and Japanese Electronic Industry. *Organ Sci*, 1(1), 99-118.

[10] Ward, J.H. (1963). Hierarchical Grouping to Optimize an Objective Function. *J Am Stat Assoc*, 58, 236-244.