Tracking Choices: Computational Analysis of Learning Trajectories

Erica L. Snow
Arizona State University
Tempe, AZ, USA
Erica.L.Snow@asu.edu

Laura K. Allen
Arizona State University
Tempe, AZ, USA
LauraKAllen@asu.edu

G. Tanner Jackson
Arizona State University
Tempe, AZ, USA
TannerJackson@asu.edu

Danielle S. McNamara
Arizona State University
Tempe, AZ, USA
Danielle.McNamara@asu.edu

ABSTRACT
This study investigates how variations in students' trajectories within the tutoring system, Writing Pal, varied as a function of individual differences and ultimately related to changes in the quality and linguistic properties of prompt-based essays. Forty-two college students interacted freely with the computerized writing tutor for approximately 4 hours. Using a novel statistical technique (random walks), we visualized students' self-paced trajectories within the Writing Pal system interface. Analyses revealed that students' self-reported perseverance was predictive of more systematic interaction patterns. Students' interaction patterns did not directly influence the quality of their writing; however, students' trajectories within the system was related to changes in the fine-grained linguistic properties of their essays. These findings demonstrate the potential for random walks to provide researchers with a wealth of information about students' interactions and subsequent learning outcomes within adaptive learning environments.

Keywords
Intelligent Tutoring Systems, random walks, natural language processing, prompt-based writing

1. INTRODUCTION
Intelligent Tutoring Systems (ITSs) are sophisticated learning environments that provide students with individualized pedagogical instruction. This customized instruction is often based on variations in students' performance and ability levels [1]. For instance, many ITSs use students' previous knowledge and current skill levels to build user models specific to each student. These models are then tweaked and corrected through students' interactions within the system [1].

This level of customization affords students unique learning trajectories that often vary as a function of individual differences [2 - 3]. Indeed, researchers have shown that numerous individual differences can influence the way in which students interact and perform within ITSs [2 - 3]. One individual difference that has not been extensively studied in the domain of ITSs, and which may be important to the way in which students approach and interact with a system, is perseverance. This characteristic may be especially important for adaptive environments that provide students with an abundant amount of tasks that are scaffolded in a specific way. Previous work has shown that a student's perseverance is related to their ability to regulate their behaviors and achieve long-term goals [4]. Thus, if a student has high perseverance, they are more likely to continue learning tasks until the work is complete.

As students' experiences and trajectories vary, researchers are afforded a unique opportunity to examine the optimality of various learning paths within adaptive environments. To examine the efficacy of different routes within an adaptive environment, methodologies are needed that capture the nuanced ways in which students interact with ITSs across time. Dynamical analysis techniques offer researchers a unique means of visualizing and characterizing students' trajectories within these complex systems. These techniques focus on the fluid and complex interactions that are often missed by traditional static measures. Previous work with dynamical analyses has shown that these techniques can capture nuanced trends in students' choices within various adaptive environments [2]. Thus, these methodologies may provide researchers with tools to capture various trajectories and their subsequent impact on learning outcomes.

1.1 Writing Pal
The Writing Pal (W-Pal) is an ITS designed to provide students with comprehensive writing strategy instruction [5]. Specifically, W-Pal focuses on providing students with various strategies for prewriting, drafting, and revising. W-Pal is broken up into eight separate modules. Each module contains animated lesson videos that are narrated by a pedagogical agent, as well as game-based practice and essay writing practice. The design of W-Pal scaffolds students through these eight modules systematically and provides a deliberate form of instruction and practice.

1.2 Current Study
ITSs adapt to individual users' needs and abilities and often provide each user with a unique experience within the system. These varying experiences afford researchers an opportunity to examine optimal vs. non-optimal learning paths. The current study uses a novel dynamical methodology (random walks) to capture and evaluate students' trajectories within the writing tutor, W-Pal. Students were given free choice to interact with the system however they chose. W-Pal remained modular with an apparent

organization or sequence of lessons; however, no feature was locked within the system. Thus, students could "jump around" within the interface if they so chose. Using random walks, we investigated how variations in students' choice patterns varied as a function of individual differences in perseverance. We also examined how variations in trajectories impacted changes in the quality and properties of students' writing.

2. METHODS

2.1 Participants

The participants included 42 college students from a large university campus in the Southwest United States. The students were, on average, 19.2 years of age, with the majority of students reporting their grade level as college freshman. Of the 42 students, 57% were female, 53% were Caucasian, 14% were Asian, 9% were African-American, 14% were Hispanic, and 10% reported other nationalities.

2.2 Procedure

The participants completed 4 sessions (6 hours total) including a pretest, strategy training within W-Pal, and a posttest. During the pretest (session 1), students completed questionnaires including measures of motivation, perseverance, and expectations of technology. Within the pretest, students were also asked to compose a timed (25-minute) essay in response to an SAT-style prompt. During training (sessions 2 and 3), students spent approximately 4 hours interacting freely within the system interface. The interface of the W-Pal system was entirely unlocked during training. The modules within W-Pal were still in an instructional scaffolding format; however, students were free to interact in the system however they saw fit. Finally, at posttest, students completed a battery of questionnaires similar to those in the pretest and composed a timed (25-minute) essay in response to an SAT-style prompt. Essay prompts were counterbalanced across pretest and posttest.

2.3 Measures

2.3.1 Writing Performance

During pretest and posttest, students were asked to write a timed (25-minute) SAT-style essay in response to a prompt. The quality of each student's essay was assessed through the use of an NLP algorithm [6]. This algorithm assigns essay scores on a 1 to 6 scale ranging from "Poor" to "Great."

2.3.2 Linguistics Features

To assess the linguistic features of the pretest and posttest essays, we utilized Coh-Metrix. Coh-Metrix is a computational text analysis tool that calculates linguistic indices at lower and higher-levels of given texts. The lexical indices in Coh-Metrix include word-level information, such as lexical diversity and word frequency. Syntactic measures comprise indices related to the complexity of sentences constructions, such as the number of modifiers per noun phrase and the incidence of agentless passive constructions in a text. Cohesion measures indicate connections between ideas in a text; some relevant measures include: incidence of connectives and content word overlap (for adjacent sentences and all sentences). Finally, Latent Semantic Analysis (LSA) is used to provide information about the semantic similarity of texts.

2.3.3 Perseverance

Students' perseverance was measured using the Duckworth et al. (2007) Grit scale [4]. This measure comprises 8 short questions designed to capture students' willingness to persist at tasks and persevere in the face of failure.

2.3.4 System Interaction Choices

Within the W-Pal system, students can chose to interact with a variety of features that fall into one of three categories. Each of these categories represents a different type of functionality within W-Pal; these functionalities are *lesson videos*, *game-based practice*, and *essay practice*.

2.5 Data Processing

Students' data logs from their interactions with W-Pal were used to trace and categorize every interaction into one of the three previously mentioned category types: lesson videos, educational games, and essay practice. Tracking students' choices with these three distinct features affords the opportunity to investigate patterns in students' choices during their time within the system. This is especially important given that the system interface was completely unlocked during training. Thus, this categorization provides a stealth means of assessing students' behaviors and corresponding trajectories when they are free to claim agency over their experience.

3. QUANTITATIVE METHOD

To examine variations in students' behavior patterns within W-Pal, random walks were conducted. This analytical tool provides a means to visualize students' trajectories within the system. The following section provides a brief description and explanation of random walks.

It can be difficult to visualize fine-grained patterns that emerge within categorical data. One mathematical tool that can provide researchers with a spatial representation of such patterns is a random walk [2]. Random walks were used within the current study to visualize and capture the fluctuations within students' interaction patterns in W-Pal. These patterns emerged through the sequential order of students' interactions with the three feature categories (i.e., lesson videos, educational games, and essay practice). To create a spatial representation of students' trajectories within the system, each category is given an arbitrary assignment along an orthogonal vector in an X, Y scatter plot. These assignments were as follows: educational games (0,1), lesson videos (1,0), and essay practice (0,-1). These vectors are random and not associated with any qualitative value; instead, they simply provide an orthogonal grid where we can view patterns of system interactions. Random walks have previously been used to trace students' interaction patterns within the game-based ITS, iSTART-ME [2].

To generate a visualization of students' time in the system, we created individual walks for each student by placing an imaginary particle at the origin (0,0). Then, using log data we moved the particle in a manner consistent with the vector assignment, which effectively assigns a movement to students' interaction choices within the system. The resulting walk is a combination of students' "movements" and thus gives us a fine-grained look at each student's trajectory within the W-Pal system.

To illustrate what a random walk might look like for a student within the W-Pal system, see Figure 1. The starting point for all students' walks is (0,0) where the horizontal and vertical axes intersect. In the example provided in Figure 1, the student's first interaction was a lesson video; so, the particle moves one unit to the right along the X-axis (see # 1 in Figure 1). The student's second interaction was with an educational game; thus, the particle moved one unit up along the Y-axis (see # 2 in Figure 1). The student's third interaction was another lesson video, which again moves the particle one unit right along the X-axis (see # 3 in Figure 1). The student's fourth and final interaction choice was essay practice, which moved the particle one unit down along the Y-axis (see # 4 in Figure 1). These simple rules allowed us to generate unique random walks for each of the 42 students.

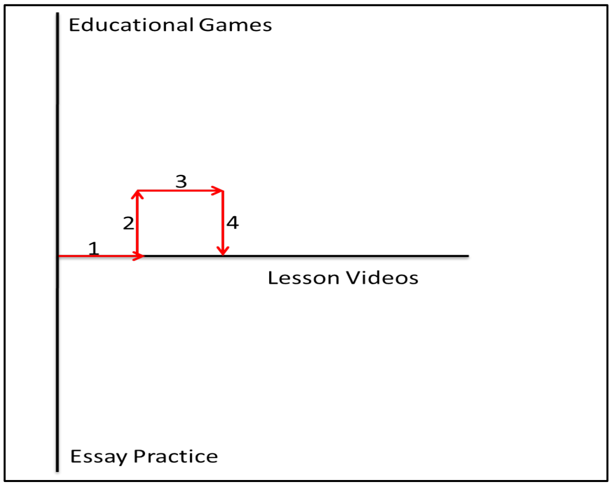

Figure 1. Example Random Walk within W-Pal

4. RESULTS

Students in the current study were free to interact with the W-Pal system in any way they saw fit. Using log data, we classified students' interactions into one of three possible categories (i.e., lesson videos, educational games, and essay practice). To examine how students interacted with the system, we calculated the total frequency of students' interactions with each of these three categories. On average, students made 19 interaction choices and spent the majority of the time watching lesson videos (73%) and playing games (26%). Only two students chose to interact with the essay practice; however, neither wrote more than two sentences before choosing to interact with a different feature (i.e., lesson video or educational game). As a result of these frequency analyses, we condensed our random walks to only include the X and Y coordinates associated with the lesson videos and educational games.

To examine students' patterns of interactions within the W-Pal system, log data were used to create a unique random walk for each student. These walks construct a visual representation of each student's unique interaction trajectory. We then calculated a slope for each student using the x and y coordinates embedded within their unique random walk (*M*=.23, *SD*=.14, Range= .00 - .46). Students' interaction trajectories (i.e., their slopes) inform us about the way in which students engaged in the system when everything was unlocked and they could "jump around" from module to module. These slopes serve as a coarse measure of each student's unique trajectory within the W-Pal system. Although slope analysis can obscure some of the variability in each student's unique walk, this metric provides valuable insight into the development of students' trajectories across time.

W-Pal was originally designed to be modular in nature thereby scaffolding students through systematic strategy instruction. Thus, this ordered design creates its own unique system trajectory. Using only lesson videos and educational games, we calculated a random walk for the system that represented the designed instructional scaffolding. We then computed a slope analysis to obtain the trajectory of the random walk that would be generated if students went through the system as designed (i.e., no skipping around). Thus, through the use of random walks we were able to look at differences between designed scaffolding trajectories (i.e., how researchers intended the system to be used) and students' trajectories (i.e., the way students' chose to use with the system).

Results from the slope analysis revealed that the system trajectory had a slope of .52. Interestingly, the highest slope value for any student was .46; thus, no one student went through the system exactly as it had been designed, although many students came close, thus skipping around the interface very rarely. In the current study, we hypothesized that students' self-report ratings of perseverance would be related to the way in which they approached the system. Utilizing these slopes, we examined the relation between slope magnitude and individual differences in perseverance. A correlation analysis revealed that the magnitude of walk slopes was positively related to students' self-reported perseverance (r=.332, p=.032). Thus, students who reported a higher likelihood to persevere (i.e., high Grit) demonstrated a more vertical trajectory, which more closely matched the system trajectory. A median split was calculated on students' pretest self-reports of perseverance (i.e., grit) to produce a visualization of the differences in system trajectories based on students' self-reported perseverance (Figure 2). This split produced two groups: *low grit* and *high grit* students, with low grit students represented as the red slopes and high grit students represented by green slopes. Within Figure 2, the black slope represents the system trajectory. This visualization supports the correlational results by revealing that high grit students (green slope) were much more likely to interact in a pattern similar to the designed instructional scaffolding (black slope).

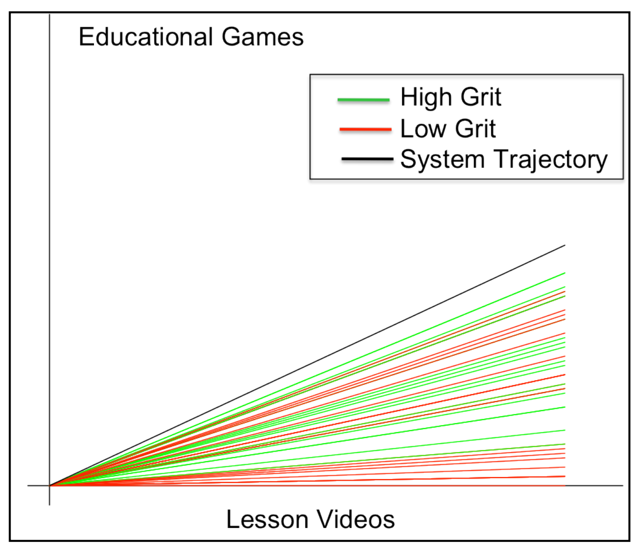

Figure 2. High and Low Grit Trajectory Comparison

To assess the relation between students' system trajectories and essay quality, Pearson correlations were conducted using students' random walk slope and their pretest, posttest, and total gain essay scores (i.e., posttest – pretest). Results from this analysis indicated that students' trajectories within the system showed a marginal negative relation to the quality of their pretest essays (r=-.291, p=.061). However, there was no significant relation between students trajectories in the system and the quality of their posttest essays (r=-.072, p=.649) or their holistic gain scores in essay quality (r=.188, p=.234).

Although there was no relation between students' trajectories and essay quality, we hypothesized that variations in students' trajectories within the W-Pal system might be related to changes in their essays at a more fine-grained size. We utilized Coh-Metrix to analyze the linguistic features of students' pretest and posttest essays. We then calculated a change score in the linguistic features (i.e., posttest – pretest) that indicated the extent to which linguistic features within the essays changed across the two assessments. Four Coh-Metrix change variables were significantly correlated to students' trajectories within the system. These variables were incidence of pronouns (r=-.381, p<.05), paragraph length (r=.331, p<.05), LSA paragraph to paragraph (r=.312, p<.05), and content word overlap (r=.371, p<.05).

To examine these relations further, a stepwise regression analysis was calculated to predict students' system trajectories from changes in the four Coh-Metrix variables that exhibited significant correlations with students' interaction trajectories. Two linguistic variable change scores were retained in the final model and combined to predict 27% of the variance in students' trajectories [$F(1,39)$=6.69, p=.014; R^2=.27]: noun incidence change [B=-.359, $t(1,39)$ = -2.61, p=.012] and content word overlap change [B=.353, $t(1,39)$=2.57, p=.014]. Overall, this analysis indicated that when students' system trajectories resembled the actual system design, they were more likely to increase their local cohesion and substantive content of their essays.

5. DISCUSSION

ITSs are designed to provide customized instruction to students based on their individual needs and abilities [1]. This individualized instruction can often lead to students experiencing different learning trajectories within a given system. The emergence of these various learning trajectories has led researchers to begin to examine ways to investigate optimal versus non-optimal learning paths. One way to examine optimality within an adaptive environment is to examine how learning gains vary as a function of the trajectories students take within a system.

The current study made use of a novel methodology by employing random walks to capture and visualize students' unique interaction patterns within W-Pal. Random walk analyses revealed that students who interacted with the system in a more systematic way (i.e., closer to the designed instructional scaffolding) were also students who had higher perseverance scores. This indicates that students who jumped around the system more and did not follow the intended instructional scaffolding were individuals who reported having less perseverance. These results fall in line with previous work that has shown that individual differences influence learners' trajectories within adaptive environments [2 - 3].

Results from this study also revealed how learners' trajectories in the system influenced the quality and linguistic features of their writing. Overall, writing quality was not related to students' in-system trajectories. Interestingly, some changes in linguistics were related to students' trajectories within the system. Most notably, as students engaged in a trajectory that more closely resembled the designed system instructional scaffolding, their essays became more cohesive. Thus, these students' essays at posttest increased in the connecting of ideas.

Overall, the analyses presented here provide some promise that random walks are valuable data analytic and visualization tools that can shed light upon various behavioral trends exhibited by students. Indeed, through the use of dynamic methodologies, researchers may be able to better trace and ultimately recognize optimal versus non-optimal learning trajectories. These techniques also afford researchers the opportunity to investigate the efficiency of their system design.

5. ACKNOWLEDGEMENTS

This research was supported by the Institute for Educational Sciences (IES R305A080589). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the IES.

6. REFERENCES

[1] Vanlehn, K. 2006. The behavior of tutoring systems. *International journal of artificial intelligence in education*, 16 (2006), 227-265.

[2] Snow, E. L., Likens, A., Jackson, G. T., and McNamara, D. S. 2013. Students' walk through tutoring: Using a random walk analysis to profile students. In S. K. D'Mello, R. A. Calvo, and A. Olney (Eds.), *Proceedings of the 6th International Conference on Educational Data Mining*, (Memphis, Tennessee, July 6 -9, 2013), Springer Berlin Heidelberg, 276-279.

[3] Snow, E. L., Jackson, G. T., Varner, L. K., and McNamara, D. S. 2013. The impact of performance orientation on students' interactions and achievements in an ITS. In C. Boonthum-Denecke & G. M. Youngblood (Eds.), *In Proceedings of the 26th Florida Artificial Intelligence Research Society Conference* (St. Petersburg, FL, May 21 – May 25, 2013). FLAIRS-26. AAAI Press, 521-526.

[4] Duckworth, A. L., Peterson, C., Matthews, M. D., and Kelly, D. R. 2007. Grit: perseverance and passion for long-term goals. *Journal of personality and social psychology*, 92 (2007), 1087.

[5] Roscoe, R. D., Snow, E. L., Brandon, R. D., and McNamara, D. S. (2013). Educational game enjoyment, perceptions, and features in an intelligent writing tutor. In C. Boonthum-Denecke & G. M. Youngblood (Eds.), In *Proceedings of the 26th Florida Artificial Intelligence Research Society Conference* (St. Petersburg, FL, May 21 –May 25, 2013). FLAIRS-26. AAAI Press, 515-520.

[6] McNamara, D. S., Crossley, S. A., and Roscoe, R. D. 2013. Natural language processing in an intelligent writing strategy tutoring system. *Behavior Research Methods,* 45, (2013) 499-512.