Effects of Level Trajectory on Mathematical Gameplay

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Abstract: We investigate the effect of free-choice versus adaptively recommended level trajectories on gameplay for middle-school learners playing a 3D architectural game involving ratio and geometric reasoning. We compare data between groups examining students' game performance and level selection patterns to examine the potential impact of level trajectories on a learner's gameplay performance and process. Using data from an online-facilitated study (n=23) we find that students playing with an adaptively recommended level trajectory spend more of their time on the target math-related levels. We confirm this with data from an onsite-facilitated study (n=51) and propose that adaptive level recommendation guides learners toward game levels relevant to target learning objectives while allowing some freedom of choice.

Background

Designing a learning game with discrete game levels can be useful for isolating certain skills and compartmentalizing learning objectives, but with multiple game levels come sequence and presentation design choices. Story progression across levels can be linear, where players complete fixed sequences, or structured such that progression through the story emerges from and is impacted by gameplay, as designers prefer (Fullerton, 2019:101). Non-linear level trajectories can also be a function of difficulty, adapting to performance level. Level trajectory mechanisms like Dynamic Difficulty Adjustment can support overall game experience and reduce self-consciousness but may also lower a player's sense of control (Ang et al., 2017). Turning to learning games specifically, Shute et al. (2021) found that students' learning was not significantly affected by different game-level delivery, including four methods: adaptive, linear, free choice, and a control group. In their study involving a 2D physics sandbox game, game performance measures (e.g., levels completed) was not affected by the type of level trajectory, but rather the type of support—physics animations were found to have the most positive effect (Shute et al., 2021). We revisit the question of level trajectory effects in a 3D math game, exploring differences between (1) students freely choosing levels and (2) students recommended levels based on their competency.

Method

Study Procedure

In a 3-week experimental group-comparison study, 21 students each completed 7-9 thirty-minute gameplay sessions during a summer school program, monitored by teachers on site and facilitated by research team members by Zoom. To confirm our initial findings, we analyzed data from a later fall study, with onsite facilitators, a larger group of middle-school students (open-path: n=26, recommended-path: n=25), and more gameplay (fifteen 45-minute sessions). All students in the summer and fall studies began gameplay with 5 movement training levels (not involving the target math objectives) to familiarize themselves with basic movement and manipulation of objects in the 3D game world. We randomly assigned students to path "open-level," where students complete training levels and then choose which game level to play next, or "recommended-level," where a Bayesian network recommends levels via student performance on learning objectives in previous levels' game actions.

Results

Students in the open-level and recommended-level paths showed similar group averages for total level attempts, successful level attempts, and % of successful level attempts. Inferential statistics were used to assess the remaining three metrics, which appeared to differ between groups (time spent on movement training, total gameplay time, and % of time spent on movement training). An independent samples t-tests comparing open- and recommended-level paths for all 6 gameplay-related metrics revealed no difference between groups except for percent of time spent on movement training. As Table 1 shows, percent of time spent on movement training was over 20% higher for the open-level path with marginal significance ($t = 2.26$, $df = 22$, $p = 0.03$) and a large effect size (Cohen's $d = 0.93$, Hedges $g = 0.86$). Levene's test for homogeneity assumption showed that group variances did not differ significantly for any of the measures we investigated.

Table 1
Game Performance Statistics for Students in Two Level Trajectory Paths (Online Facilitation)

	Open n = 11	Recommended n = 10	t	df	Sig. 2-tail	Mean Difference	SE Difference
Total level attempts	10.85	11.1	-0.66	22	0.52	-1.97	2.99
Successful level attempts	6.31	7.90	-1.25	22	0.23	-2.60	2.08
% of successful levels	60.77%	64.40%	-0.37	22	0.572	-4%	0.09
Movement training time	29.93	35.31	-0.62	22	0.54	-5.29	8.50
Total gameplay time	44.58	61.73	-1.23	22	0.23	-21.49	17.41
% of time spent on movement training	84.43%	63.80%	2.26	22	0.03*	24%	0.10

Note. *Significance threshold of $p<0.05$; time is reported in minutes.

As seen above, groups did not differ significantly in the other measures. We ran t-tests to assess whether the significant difference in % of time on movement training between groups held for both females and males. For males, the difference was marginally significant ($t = 1.956$, $df = 10$, $p = 0.079$), while for females, there was no significant difference ($t = 1.201$, $df = 10$, $p = 0.257$). To confirm this finding, we ran another independent samples t-test on data from middle school learners playing the same game in the onsite-facilitated study, this time with more students, more gameplay, and more careful facilitation (i.e., on-site). As seen in Table 2, students in the recommended path spent around 7% less of their gameplay time on non-math training levels.

Table 2
Game Performance Statistics for Students in Open-level and Recommended-level Paths (On-site Facilitation)

	Open-level mean n = 26	Recommended-level path mean n = 25	t	df	Sig. 2-tail	Mean Difference	SE Difference
% of time on movement training	24.63%	13.48%	2.70	49	0.01*	11.16%	4.13
% of level attempts movement training	31.92%	19.92%	2.67	49	0.01*	12.00%	4.49

Note. *Significance threshold of $p<0.05$; time is reported in minutes.

Discussion

One reason recommended-path students spent 7% more of their time on content-related levels may be that whereas students in the recommended-level path only saw new level choices appear as they completed levels, students in the free path had to navigate multiple menu steps to find new levels. If a student is drawn to readily visible levels, level recommendations would encourage new levels by displaying them and not requiring extra menu navigation. Second, unlike game levels, training levels lacked math problem solving. If students meet challenging game levels beyond their competency they may opt for the training levels which they can confidently complete. Students recommended levels adapted to their math competencies are likely more comfortable attempting new levels. We recommend designers consider an adaptive difficulty-driven level trajectory with recommendations to maximize learners' engagement with challenging content-related game levels, while giving learners freedom of level choice.

References

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