Individual Versus Shared Design Goals in a Graph Construction Activity

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Abstract: Technologies can help foster diverse ideas in collaborative learning activities by taking advantage of group members' unique ideas and perspectives. Assigning individual group members to specific tasks may promote this diversity. In this paper, we introduce a graphing challenge, in which student pairs construct graphs to represent the motion of an amusement park ride. We assigned pairs to experimental conditions with either *individual* design goals or *shared* design goals. Analysis revealed that students with *individual* design goals demonstrated deeper engagement with one of the design tasks (i.e., to create a "safe" ride), while this goal was relatively neglected when goals were *shared*. No impact of condition was found on posttest learning; however, students demonstrated overall gains.

Introduction

In collaborative learning groups, technologies can elicit a diverse range of ideas by facilitating expression of individuals' unique perspectives. Supporting individual voices within groups enables equity, particularly for students from non-dominant cultural backgrounds who may otherwise be reluctant to engage (Rosebery, Ogonowski, Dischino, & Warren, 2010). Moreover, the expression of diverse ideas provides an opportunity for learning when students reconcile conflicting perspectives (Gijlers & de Jong, 2009). In complex, inquiry-based learning activities the process of distinguishing and reconciling conflicting ideas promotes coherent understanding (Linn & Eylon, 2011). Therefore, collaborative learning activities can take advantage of collaboration by eliciting conflicting beliefs, and then managing their resolution. Yet, if group members begin an activity with similar ideas or if a single member adopts a dominant role, these opportunities are limited. For example, Clark, D'Angelo, and Menekse (2009) found that groups manufactured to ensure conflicting ideas between students demonstrated greater learning than groups constructed at random. Alternatively, in cases of intact groups, technology can support more dynamic collaboration by assigning (personalizing) responsibilities for specific students (Kollar, Fischer, Hesse, & Media, 2006). By supporting unique engagement patterns for each group member, these activities provide opportunities for productive discussion of conflicting ideas. In this paper, we present a comparison between individualized and shared goals in a collaborative design activity in which students construct graphs to represent the motion of an amusement park ride.

Goals in design activities

According to the knowledge integration framework (Linn & Eylon, 2011), activities support learning by guiding students to elicit ideas, discover new ideas, distinguish between these ideas, and reflect on these ideas to develop a coherent understanding. Collaborative activities fit well within this framework because they are able to expose a broad range of student ideas and provide opportunities for distinguishing between potential conflicts. For this reason, curricula developed within the knowledge integration framework are typically intended for small groups of students (Linn & Eylon, 2011). Because learning environments such as the Web-based Inquiry Science Environment (WISE) can assign diverse roles, by name, during knowledge integration activities, they represent an opportunity to investigate how collaborative patterns impact learning.

In particular, in design projects, where students are expected to generate artifacts creatively, patterns of collaboration are likely to have a substantial impact on how artifacts are generated. When materials are limited (e.g., a single computer keyboard), tasks must inevitably be divided among group members. Without external structuring, group members negotiate duties according to personal (i.e., "internal") collaboration scripts about how tasks should be divided (Kollar, Fischer, & Slotta, 2007). In some cases, this leads to equitable participation, but in other cases participation may be unbalanced. To promote equitable engagement the teacher or software may assign specific responsibilities to each group member (Kollar et al., 2006). A common approach is to assign roles, which divide the overall activity into distinct tasks. For example, in an online discussion activity (Cesareni, Cacciamani, & Fujita, 2016) assigned students to roles of "social tutor", "synthesizer", "concept mapper" and "skeptic". While this approach may ensure accountability for each of the group members, it may not take advantage of students' diverse ideas about shared content.

Alternatively, assigning unique priorities or goals within shared tasks is a common practice in business and engineering design activities to encourage diverse perspectives (Détienne, 2006). In cases where inherent tradeoffs exist in the design, assigning individuals to focus on alternative features may make these tradeoffs more salient. For example, in this study we assign group members to focus on conflicting "safety" and "thrill" concerns for an amusement park ride that they are designing. By helping students evaluate and resolve conflicts centering around important structural features of their design, we can direct attention to central issues. In contrast, students may pay attention to superficial characteristics in unguided projects (Hmelo-Silver, Duncan, & Chinn, 2007).

Yet, there is risk in "over-scripting" collaboration (Dillenbourg, 2002). If expectations for a task are prescribed in a step-by-step manner, students may miss the opportunity to recognize and evaluate competing ideas. Furthermore, if assigned responsibilities are not aligned to students' preferences or internal collaboration scripts, they may resist external scaffolds (Kollar et al., 2007). As a result, creating productive roles for group members requires attention to students' actual processes when given specific assignments.

Study goals and significance

We investigate the personalization of design goals within an online inquiry unit conducted in a classroom setting. The online environment provides us with the opportunity to directly present a design goal to an individual student, by name. We compare groups who are randomly assigned to either *individual* or *shared* design goals. Our aim is to investigate whether assignment alters the artifacts that students build and the concepts they learn. In particular, we study the following two research questions:

1. How do *individual* and *shared* design goals impact the artifacts of design?
2. How do *individual* and *shared* design goals impact learning of underlying concepts?

By addressing these questions we seek to contribute a new approach to the collaboration scripts literature (Dillenbourg, 2002) in the context of student design projects.

Methods

Participants and procedures

We performed this study with five participating teachers from two schools. All but one of these teachers had prior experience running similar online inquiry projects as part of a research study. In spite of their similar prior experience with collaborative inquiry projects, the teachers differed substantially (by school) on their approach to and acceptance of collaborative activities.

In school A (38% White, 31% Asian, 17% Hispanic, 4% Black, 22% Reduced-price lunch, 12% ELL), three teachers participated in this study: A1 (male, 10+ years of experience, 103 students), A2 (female, 2nd year, 125 students), and A3 (female, 1st year, 26 students). In each of these teachers' classrooms, students sat at four-person lab tables and were expected to engage in collaborative inquiry projects throughout the school year. Students in these classrooms performed all learning activities in dyads.

In school B (51% White, 9% Asian, 28% Hispanic, 3% Black, 32% Reduced-price lunch, 7% ELL), two teachers participated in this study: B1 (female, 10+ years of experience, 126 students), and B2 (male, 10+ years of experience, 103 students). In both of these teachers' classrooms students sat in rows of desks facing the front of the classroom. These teachers both expressed skepticism about collaborative activities (e.g., assuming they promote off-task activity) and preferred to assign tasks individually. At the teachers' request, students in these classrooms performed the first part of the learning activity ("Graphing Stories") individually, and then were grouped in dyads to perform the collaborative challenge activity.

In all classes students completed a pretest and posttest individually.

Materials

All materials were presented in the Web-based Inquiry Science Environment (WISE).

Graphing stories

In this set of activities students construct position vs. time graphs to correspond to simple stories of motion (e.g., a hike in the woods). See previous work for more details (Vitale, Lai, & Linn, 2015).

Amusement park challenge

In this challenge activity dyads of students are randomly assigned to either *shared* or *individual* conditions to complete the following (http://wise.berkeley.edu/previewproject.html?projectId=18233):

1. Join the team. In this challenge students design an amusement park ride by constructing graphs of position vs. time. In the *individual* condition, students are uniquely assigned to a single goal, embodied by either the *safety* or *thrill* team (Figure 1). In the *shared* condition, students read instruction that they will be working together for both teams. Following this introduction, students are asked either individually or as a group to describe how a thrilling and a safe ride would differ from each other.

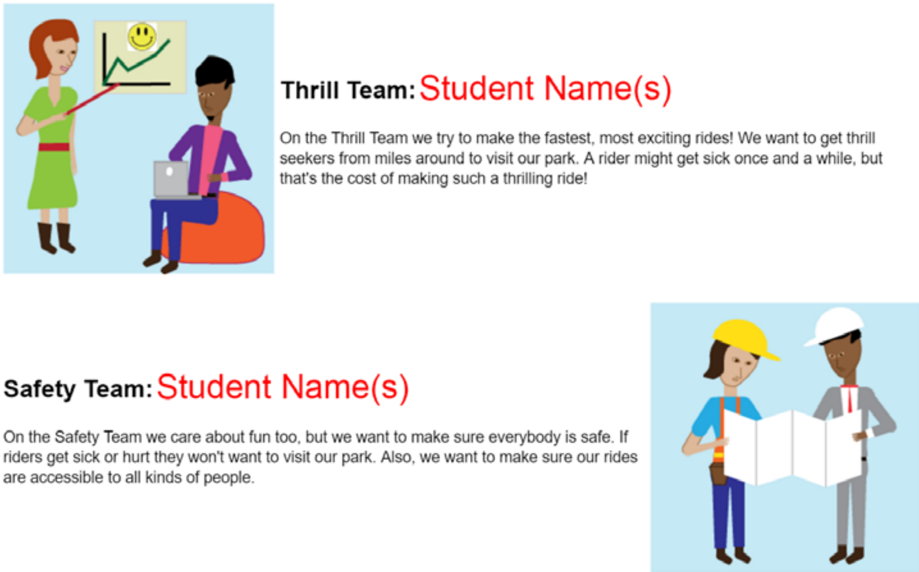


Figure 1. Introduction to design goals in *Amusement Park Challenge*. In *individual* condition, each student in the workgroup pair is assigned to either the "thrill team" or the "safety team" by name. In the *shared* condition, both students are referred to, by name, next to each of the teams.

2. Graphing curves. Like the *Graphing Stories* curriculum, the primary activity in the *Challenge* is to construct a graph and observe the corresponding motion on a linked simulation. However, building on *Graphing Stories,* students are afforded the additional ability to modify the curvature of segments, thereby impacting acceleration. To introduce this new feature, students are asked to construct a single line segment, modify the curvature in both directions, and observe the impact on the animated ride. Additionally, to emphasize the significance of acceleration, movement of the head of the rider is accentuated forwards or backwards, based upon the acceleration. For example, in Figure 2, the rider is experiencing negative acceleration (slowing down), and is therefore learning forwards. Individualized roles are not utilized for this step.

3. Design each ride. In this step groups design two rides: one that is "thrilling" and one that is "safe". The students are not given precise criteria, but are expected to follow their own definition of each. Prior to constructing a graph, students are prompted with a question, "What are you trying to design?", to which they could respond by selecting either "a thrill ride" or "a safe ride". Following selection, students construct a graph with up to five segments, and then observe the corresponding ride (Figure 2). Following completion of a ride (once the animation was observed), students can press the "New" button to clear the graph. They would again be prompted to indicate the type of ride. In the personalized condition students are asked to construct each of these ride designs individually, although the partner was still available for assistance. In the *shared* condition students are expected to work on all tasks together.

The separate "thrill" and "safe" ride designs are intended to highlight critical relationships in the graphs, including the link between speed and slope, acceleration and curvature. By manipulating graphs for each of these design goals students produce contrasting cases, which illustrate these relationships (Schwartz, Chase, Oppezzo, & Chin, 2011).

When students feel satisfied with each design they are instructed how to download an image of the corresponding graphs. On two later pages, one for each design, they upload these graphs for public display within a chat forum. Students are prompted to describe uploaded images (and their corresponding rides), and then comment on another groups' ride.

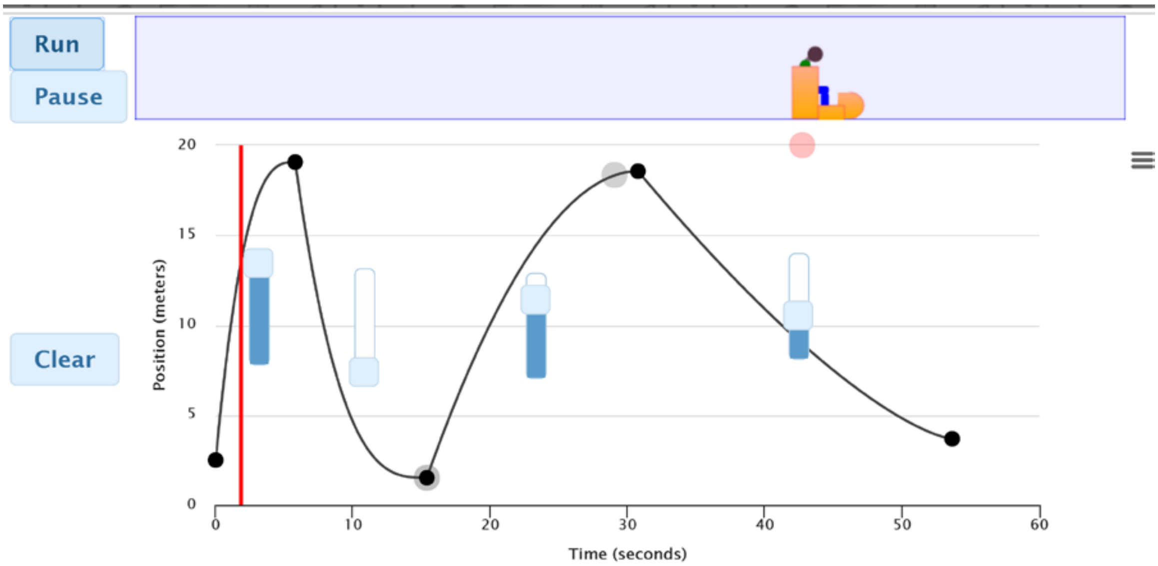


Figure 2. Amusement park challenge. Students plot points and adjust sliders to modify curvature. Upon pressing "Run" a simulation of the ride begins. A corresponding red vertical line displays the current time on the graph.

4. Design your best ride. Following their experience exploring designs for "safe" and "thrilling" rides, workgroups are prompted to construct a "best" ride that is both fun and safe. In this case, students could construct up to 10 segments. Students are, once again, prompted to save their favorite ride and upload it on a discussion board. There is no reference to individual design goals.

5. Make a final report. After completing all graphing steps students are prompted to make a recommendation about how to design rides, with graphs, that are both fun and safe.

Pretest-posttest graphing item: "Playing Pool"

Although the pretest and posttest consisted of multiple items, we focus on a single item, *playing pool* (Figure 3), which best aligns with conceptual themes of the *Challenge*. In this item (Figure 3), students are asked to select the graph that best represents a simple story about a pool (billiards) shot. Multiple choice items distinguish students' understanding of the relationship between slope of segments and speed, and between curvature and acceleration. Distractor items featuring "graph-as-picture" representations are also included.

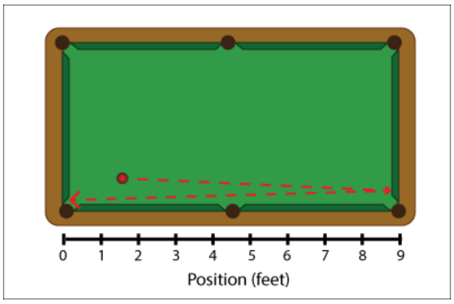
Posttest collaboration survey

To assess students' understanding of their collaborative strategies we prompted students with the following open ended questions at the end of the posttest:

1. Describe how you and your partner worked together on the Amusement Park Challenge. Did you each take on different roles and responsibilities? If so, describe your role in the group.
2. Describe one example of a time during the Amusement Park Challenge where you and your partner had to make a decision, but each of you had different ideas. How did you make this decision?
3. Describe one example of something you would have done differently during the Amusement Park Challenge if you had been working on your own.

Mel placed a ball about one and a half feet from the edge and hit the ball across the table. The ball went all the way to the end, bounced all the way back, and fell into the hole in the corner pocket. The shot took about 3 seconds.

Which of the following Position vs. Time graphs best represents Mel's shot?



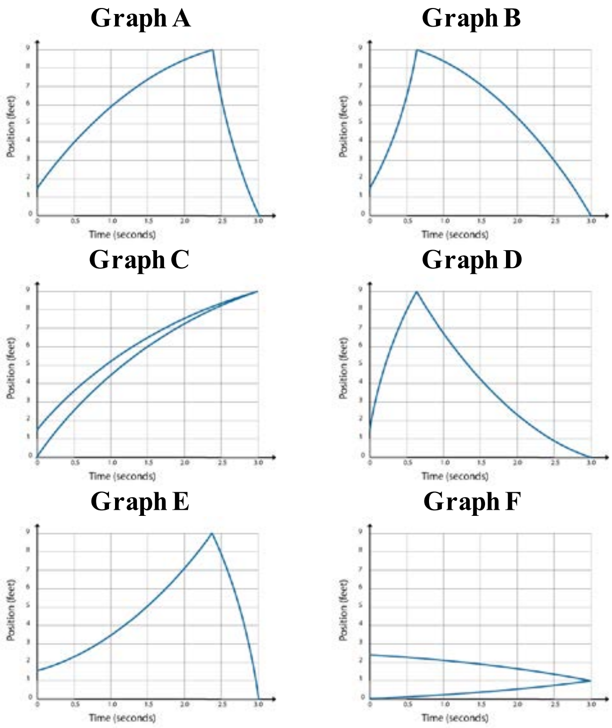


Figure 3. "Playing Pool" pretest and posttest item. The correct response (Graph D) illustrates a faster speed (steeper slope) on the path to the wall than back to the hole and negative acceleration (decreasing speed).

Analysis method

The pretest-posttest item was scored according to a knowledge integration rubric (scores 1 – 6). This approach has been used in previous graphing applications (Vitale et al., 2015) to emphasize links between narrative elements of the item (e.g., the "speed") and spatial elements (i.e., the slope).

Graph artifacts were stored digitally by tracking the position of each vertex and the curvature of the segment, as given by the value of the corresponding slider. A graph was marked as complete if students ran the corresponding animation. Using this information, we analyze several features of each graph, including the average angle of segments and the number of segments. Additionally, for *design each ride* data logs indicate whether a graph was intended to be a "thrill" or "safe" ride (i.e., "type"). We analyze the impact of ride type and condition on graph features (e.g., average segment angle). To reflect likely covariation of features for "thrill" and "safe" rides made by a single workgroup we use linear mixed effects models with a random intercept for workgroup, for both continuous and ordinal outcomes. We report on both the statistical significance of predictors as well as the standardized regression coefficients or odds-ratio (for ordinal variables).

Findings and analysis

Artifact design

To get an initial sense of how students perceived the difference between "safe" and "thrill" rides we analyzed student descriptions of each type of ride in *Join the Team*. After processing the 275 responses to remove common words, we found that for "thrill" rides meaningful, frequent terms included, "fast" (185), "drop(s)" (136), "loop(s)" (124), "upside" (52), "turn(s)" (63), "speed(s)" (64), and "steep" (28). In this case students were often considering features of roller coasters that were not relevant to the ride they were designing (e.g. loops); however, words such as "fast" and "speed" were relevant. Very few terms that clearly relate to acceleration emerged, but perhaps include "sharp" (14) and "sudden" (11). Likewise, for safe rides, frequent terms included, "(seat)belt(s)" (151), "bar(s)" (63), "harness(es)" (24), "speed" (15), and "slow" (13). Clearly, students interpreted "safety" in terms of protecting riders from impact, although some did make reference to speed.

To compare emphasis on each design goal, we computed a count of the number of complete graphs made for each type, for each workgroup, and compared these by condition. In the *individual* condition group members averaged 3.1 (SD = 2.9) "thrill" graphs and 2.5 (SD = 2.2) "safe" graphs. In the *shared* condition group members averaged 3.6 (SD = 2.8) "thrill" graphs and 1.9 (SD = 2.0) "safe" graphs. A mixed effects model of graph count, using 222 workgroups, reveals a significant effect of graph type (is safe) [$\beta = -0.31$, $t = -5.9$, $p < .001$), no main effect of condition (is *individual*) [$\beta = -0.08$, $t = -1.2$, $p = .2$], and a significant interaction of condition and graph type (is safe and *individual*) [$\beta = 0.16$, $t = 2.4$, $p = .02$]. The interaction indicates that the proportion of safe rides was higher (but still less than ½ of all ride designs) when design goals were *individual* than when they were *shared*.

A higher proportion of safe rides in the *individual* condition suggests more engagement with the safe task. Another proxy measure of engagement is the complexity of the graphs. To analyze this, we restricted analysis to final graphs and categorized complexity by number of segments (0: none, 1: small, 2+: large). An ordinal mixed effects model of complexity, using 209 workgroups with completed graphs, reveals a main effect of graph type (is safe) [odds-ratio = 0.38, $z = -2.6$. $p = .009$), a trend towards a main effect of condition (is *individual*) [odds-ratio = 0.51, $z = -1.7$, $p = .09$], and a significant interaction of condition and graph type [$\beta = 3.5$, $z = 2.3$, $p = .02$]. This indicates while safe rides were likely to be less complex than thrill rides overall, the odds of a more complex safe ride were higher in the *individual* condition than the *shared* condition.

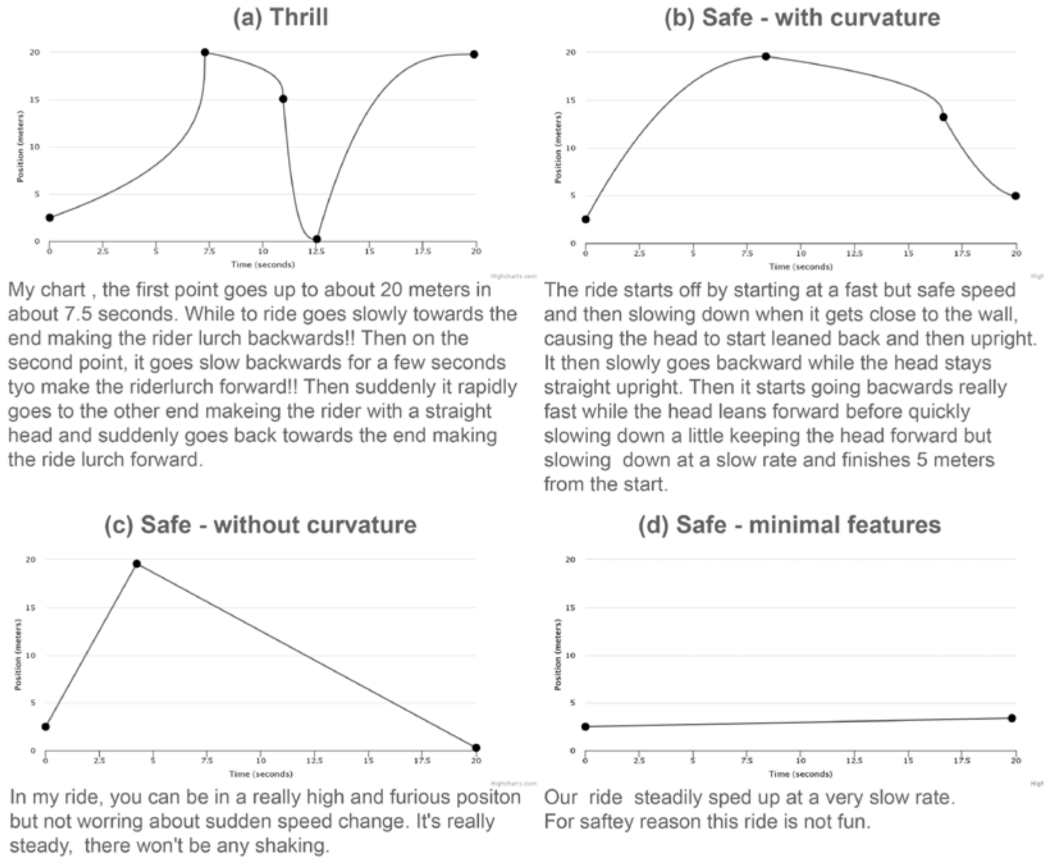


Figure 4. Examples of final thrill (a) and safe rides (b, c, d), with descriptions. Rides a, b, and c were designed by students in the *individual* condition, while ride d was designed by a group in the *shared* condition.

Considering students' expressed emphasis on speed as a distinguishing feature of thrill and safe rides, we evaluated the mean (absolute) angle of segments in students' final graphs. A mixed effects model of mean angle, using 209 workgroups with completed graphs, reveals a significant effect of graph type (is safe) [$\beta = -0.55$, $t = -9.2$, $p < .001$), no main effect of condition (is *individual*) [$\beta = -0.01$, $t = -0.1$, $p > .2$], and a significant interaction of condition and graph type (is safe and *individual*) [$\beta = 0.14$, $t = 2.0$, $p = .05$]. This indicates that that while, overall, "safe" rides had less steep slopes, those in the *individual* condition made steeper segments for the *thrill* ride than those in the *shared* condition.

To make sense of these finding we selected examples of final designs from students taught by a single teacher. We chose teacher A2 because her students demonstrated a high level of enthusiasm (they frequently encouraged other students, outside their group, to view their designs), and her large number of students (125) allowed us to explore a diverse range of artifacts. From these students, we chose four representative examples. The distinguishing features of thrill and safe rides in Figure 4 (a) and (b) are the slope and curvature of segments, not the number of segments. Students who produced these graphs were clearly engaged with the task. Figure 4 (c) also demonstrates a valid safe ride, although this workgroup did not take advantage of curvature. We do not know if it reflected less engagement than Figure 4 (b); however, the student authors note that the ride is "really steady", perhaps referring to the lack of acceleration during most of the ride. On the other hand, Figure 4 (d) displays a graph that likely indicates superficial engagement with the task. In contrast to instructions, the ride did not progress back and forth at least once. Moreover, the author states that the ride "steadily sped up", although the actual ride would move at a very slow, constant speed.

It may be the case that students in the *individual* condition produced fewer superficial designs because they took more personal ownership of the task, whereas those in the *shared* condition were more likely to spend their combined efforts on the more appealing task of designing a thrilling ride. Another possibility is that students who were assigned to design the safe ride abandoned their role and produced thrilling rides instead.

Posttest performance

Overall students' scores on *playing pool* rose from pretest (M = 2.7, SD = 1.0) to posttest (M = 3.3, SD = 1.2), significantly [$t(431) = 11.0$, $p < .001$]. To investigate the impact of condition on learning, we performed an ANCOVA on *playing pool* posttest scores, with Condition as an independent variable and pretest score as a covariate. This analysis shows a significant impact of pretest score [$F(1, 429) = 167.5$, $p < .001$], but no effect of condition [$F(1, 429) = 0.1$, $p > .2$], indicating that both collaborative conditions were equally effective.

To explore whether engagement in the challenge was related to learning we performed an ANCOVA on *playing pool* posttest scores with number of "safe" graphs produced by the students' workgroup, controlling for pretest score. This analysis shows a significant effect of number of safe graphs [$F(1, 429) = 26$, $p < .001$]. This suggests that students who learned more were more likely to engage in the designing activity. Conversely, since the challenge activity is the only exploration of graph curvature in the instruction, it may be that deeper involvement in the design activity promoted better understanding of non-linear graphs. For example, this student illustrates how her experience during instruction informed her response to the *playing pool* posttest item:

> I chose d because when we were doing the amusement park ride problem, the graphs looked the same… The only difference between the two [b and d] was the placement of their curves, which brought me back to the amusement park ride. I recalled that the cart went the fastest at the most inverted part of the curves, or the opposite, depending on whether they curved in or out. I assumed that the two fastest points should be when the ball is originally hit, and when it bounces off the wall. Graph d showed that the ball would start off, and slow down as it reached the top, from there, it would bounce off the wall and speed up for a bit, before slowing down again as it reached 0,0.

A lack of difference between conditions may be due to a number of factors. First, although *individual* goals produced a better balance of thrill and safe rides, it may be that designing either type of ride supported learning. In the case where students designing safe rides chose not to manipulate curvature (like Figure 4, c and d) then learning was more likely for thrilling rides so an imbalance in trials could result in more experience with curvature. Furthermore, while *individual* goals helped to structure collaboration, in many of the groups, collaborative roles emerged spontaneously. In the *shared* condition 19% of groups indicated that they divided up "safe" and "thrill" responsibilities. Additionally, 35% of participants indicated that they alternated turns or constructed alternative roles (e.g. "typer", "grapher"). Only 6% of students indicated that one group member (themselves or partner), took a dominant role. Thus, spontaneous collaborative strategies may have mimicked the advantages of the collaborative strategies implemented in the treatment.

Implications

This investigation suggests that personalized design goals can help direct engagement to specific instructional activities – including those that may be valuable, but less appealing to students. Directing students in the *individual* condition to focus on separate goals increased attention to building safe rides. Although students in the *individual* condition were more likely to engage in building safe rides, we did not find that additional focus on this task improved performance on the outcome measure. Future work is needed to determine whether personalizing priorities can foster learning by boosting engagement with tasks that are clearly aligned with learning goals. Future work can also investigate whether an even distribution of task attention could help both partners learn or whether gains are more likely for the assigned student.

More generally, the individualized design goals approach represents a tool by which teachers and designers can establish equitable student partnerships during collaborative activities. This stands in contrast to a division-of-labor strategy in which one student may select a less demanding or gender-stereotyped role. For example, in some studies boys take the role of primary computer user, particularly in game-like settings, to the disadvantage of others (Volman & van Eck, 2001). Rather, by personalizing goals, students are expected to perform tasks that engage in similar conceptual processes. By prompting them to then coordinate between two sets of goals, the students are required to take each other's contributions seriously. As complex projects become more integral in STEM classrooms (NGSS Lead States, 2013), helping students develop both individual responsibility for a project and sensitivity to their partners' ideas is essential to ensuring successful experiences.

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