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Abstract

An extensive body of work has documented the impact of analogous cases on transfer. However, far less work has explored the role of *contrasting cases* in facilitating transfer. We designed a novel contrasting cases activity to engage learners with center-of-mass concepts in an engineering design task – building a cantilever using Legos. Participants in three conditions analyzed either contrasting cases, single cases, or no cases in the midst of an engineering design activity. Contrasting cases facilitated near but not far transfer. However, all conditions built equally successful cantilevers and noticed the underlying structure of center-of-mass concepts to the same degree. Moreover, regardless of condition, participants who noticed the structure at a deeper level performed better on both the engineering task and the far transfer assessment. The work has implications for the design of science and engineering instruction, while expanding our understanding of the perceptual processes that underlie transfer.

Keywords: transfer; contrasting cases; science learning; engineering; education

Introduction

A key goal of science education is to help students transfer their understanding of fundamental scientific principles to novel situations. Unfortunately, transfer is notoriously difficult to achieve, in any domain (Gick & Holyoak, 1983; Detterman, 1993), and there is no shortage of examples of failed transfer of science concepts (Bassok & Holyoak, 1989; Georgihades, 2000; Vattam & Kolodner, 2008). This paper explores the potential of contrasting cases in facilitating the transfer of science concepts from engineering activities.

Noticing and Transfer

One reason novices fail to transfer is that they fail to notice the deep structure of problem situations and instead, are drawn to surface features that are specific to a given situation (Chi, Feltovich, and Glaser, 1981; Chi & Vanlehn, 2012). For instance, in a classic study by Gick & Holyoak (1983), few participants spontaneously transferred across problems with the same deep structure but different surface features. However, when given a hint to use what came before, most participants could correctly apply the solution from the previous problem. So it was noticing the deep structure (not applying it) that was difficult. Several theories and empirical studies argue that noticing and perceptual processes play a key role transfer (Day & Goldstone, 2012; Greeno, Smith, & Moore, 1993; Lobato, Rhodemal & Hohensee, 2012; Schwartz, Chase, Oppezzo, & Chin, 2011; Shemwell, Chase, & Schwartz, 2015).

Contrasting Cases and Transfer

One way to shape what learners notice is to give them contrasting cases. Contrasting cases are examples that differ on key deep features but share irrelevant surface features. The systematic variation in the cases can help learners notice deep structures (Bransford, Franks, Vye, & Sherwood, 1989; Gibson & Gibson, 1955), and transfer them to novel situations (Schwartz et al., 2011; Shemwell et al., 2015).

An extensive body of work has documented the positive impact of comparing analogous cases on transfer (for a meta-analysis, see Alfieri et al., 2013). However, far less work has explored the role of contrasting cases in facilitating transfer (but see Gick & Paterson, 1992; Marton, 2006; Rittle-Johnson & Star, 2007; Schwartz & Bransford, 1998). In this study, we aimed to contribute to this growing body of literature by designing and testing the effects of contrasting cases on novel content (center-of-mass concepts in physics) and in a novel context (engineering design).

Integrating Contrasting Cases and Engineering

There is a growing interest in teaching science via engineering design activities. For instance, the Next Generation Science Standards now include engineering practices as a key focus of science instruction. Engineering movements such as coding clubs, robotics, and maker labs are now spreading to K-12 and post-secondary schools (Martin, 2015). While highly motivating, these engineering design activities often lead to trial-and-error tinkering rather than careful application of underlying STEM concepts (Holbrook & Kolodner, 2000). This creates a "design-science gap," whereby learners focus mostly on the procedural aspects of building out their designs, rather than attending to the underlying science concepts (Vattam & Kolodner, 2008). To better integrate the noticing of scientific principles within engineering design activities, while facilitating critical transfer of science concepts, we sought to integrate contrasting cases instruction into an engineering design activity. We hoped that contrasting cases would help learners notice deep structures in physics, both within the complex context of a Lego-building task and in novel, non-engineering transfer situations on a paper test. Our aim was to first test the value of contrasting cases with adult learners in the lab before exploring them in the messier context of K-12 classrooms.

The Current Study

For the current study, we designed an authentic engineering design task and accompanying contrasting cases. The Contrasting Cases (CC) condition was asked to analyze the contrasting cases in between after creating an initial design. To compare the value of contrasting cases to reflection on individual cases, a common teaching technique, we created a Single Cases (SC) condition, in which learners analyzed only individual cases, in succession. A control condition, the No Cases (NC) condition, never saw any cases but instead received an extra period of Lego-building. Our hypotheses were as follows:

(1) The CC condition should demonstrate greater noticing of the deep structure of center-of-mass during learning, compared to other conditions.

(2) The CC condition should demonstrate greater near transfer than other conditions. We did not make a prediction about far transfer, given the notorious difficulty in achieving it (Detterman, 1993).

(3) Across all conditions, participants' level of noticing should predict their transfer performance.

We did not make a strong prediction about condition differences in performance on the engineering tasks. On the one hand, if participants notice the underlying structure of the concepts, they may try to apply that structure in their designs. On the other hand, people can often be successful in engineering design activities via trial-and-error.

Method

Participants

A brief pretest was given to all potential participants, and anyone demonstrating little prior knowledge of center-of-mass concepts was invited to the study. Final study participants were 63 graduate students attending a university in Northeastern America completed the study for class credit (40 were female). Participants were randomly assigned to one of three conditions: Contrasting Cases (CC), Single Cases (SC), and No Cases (NC).

Engineering Design Challenge

The engineering challenge was to design and build a freestanding cantilever that could hang 10.5" off a table using Legos. The task was designed to engage participants in exploration of the concept of center-of-mass (COM).

The COM of an object is the average position of all its matter. COM is a weighted average. It is calculated by multiplying each point mass within the object by the distance that mass is from a reference point, then dividing by the total mass of the object. Thus, an object's center-of-mass is determined by a complex interaction of mass and distance.

In this cantilever challenge, each Lego acts as a point mass, such that both the location and weight of each Lego determines the location of the cantilever's center-of-mass. Furthermore, a structure can balance just by resting on its center-of-mass. Therefore, to complete the challenge, a participant's cantilever had to optimize placement of each Lego, by distributing the large Legos as far back as possible so that the center-of-mass of the structure is as far back on the cantilever as possible so that it can balance while extending 10.5 inches off the table. Figure 1 shows some example structures built by participants, along with the optimal structure. This engineering activity is similar to the ones students receive in many engineering design curricula.

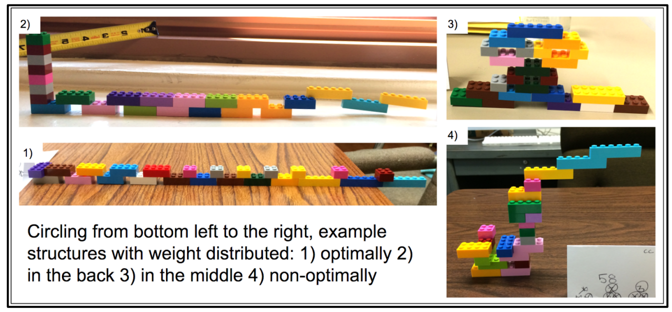


Figure 1: Example Lego Cantilever Structures.

COM can also be thought of as a balance point – the point at which an object will balance. In the prompts given to students throughout the instructional activities, "balance point" is often used to denote the center-of-mass in the context of the Lego-building activity.

Procedures and Design

In all conditions, participants engaged in an iterative design & build process, interspersed with various forms of instructional guidance. Participants completed three periods of designing and building a Lego cantilever. This iterative design & build process is popular in engineering design communities today and enabled us to incorporate measures of student noticing as the learning activities progressed.

The initial design & build period gave students a chance to explore the Legos and get their bearings on the task. After this, participants in the CC condition received a contrasting cases activity, while the SC group did an analogous activity with individual cases only. During this time, the NC group was given an extra plan-and-build phase. After this, all conditions engaged in the mid-design & mid-build periods. Another key difference between the CC group and the other conditions, is that participants were encouraged to identify differences between their prior structures and the ones they planned to build next. This served as an additional type of contrasting case prompt, whereby learners contrasted their own successive designs. After this, all participants were asked to read a textbook style passage, which explicitly taught center-of-mass concepts [1]. Then all participants

[1] While it may seem counter-productive to put the explicit instruction (the reading) at the end of the session, this mimics a form of contrasting case instruction (Schwartz & Bransford, 1998),

engaged in a third design & build phase, followed by a final reflection worksheet and then the transfer posttest.

The structure of instruction was designed to mimic good engineering design instruction used in secondary and post-secondary education, whereby iterative cycles of design are interspersed with instructional activities such as benchmark lessons, experiments, and other instructional tasks. Participants completed the study individually, in a single 1-hour session in the lab.

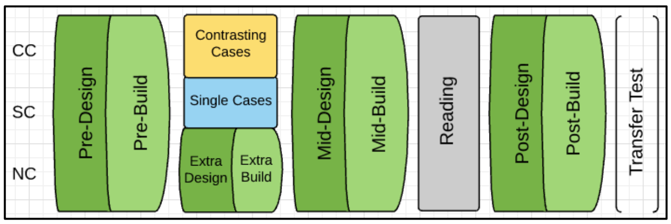


Figure 2: Study Procedure.

Instructional Materials

Designs During each design phase, participants were given 3 minutes to draw what they planned to build and answer two reflective questions. Design worksheets were kept as parallel as possible across conditions. However, to encourage the contrasting of successive builds, the CC group's design sheets asked them "How will your new structure differ from your old structure?" while the other conditions' prompts asked them to focus on their current design: "What do you like about the structure you just drew?". The second question on all Design worksheets asked learners to connect to concepts explored in the preceding instructional activity. "Based on what you learned from the activity you just completed, how will aspects of the structure you drew above affect where the *balance point* will be in the structure?"

Builds Following each design period, participants had 6 minutes to build their cantilevers. After each build period, participants' structures were broken down and participants had to start from scratch in the next build period, using the same set of Legos, rather than continue revising their existing cantilever. This was meant to encourage participants to think innovatively and be willing to start over with a new idea.

Cases Activity On the cases activity worksheet, participants were given the goal of generating a rule that would "define the location of a structure's balance point." Participants were guided to explore and use the cases to inform their rule. In the CC condition, participants were shown a set of 4 physical contrasting cases, observed as the experimenter slowly pushed each to the edge of the table to determine its balance point, and then were shown a picture of the 4 cases side-by-side comparing their balance points. Participants were then invited to compare and contrast the cases, and use what they learned from them to write their rule. Participants then analyzed a second set of contrasting cases and wrote a refined version of their rule. The contrasting cases are depicted in Figure 3. Contrasting cases were designed to contrast on the critical features of mass and distance of and to highlight how they relate multiplicatively to affect the center-of-mass. The second set of cases addresses misconceptions about irrelevant features, which we discovered in pilot work.

The SC group engaged in a similar activity, however they analyzed a single case each time before writing/revising their rule. Participants in this condition analyzed the best case from each contrasting case set given to the CC condition (e.g. the structure that stuck off the table the farthest). This is a fairly typical use of examples in science education, where learners often engage deeply with a single example or a couple of examples in succession. The NC group did not have a reflection activity. While the other conditions engaged in the cases reflection activity, the NC group completed an additional design & build period.

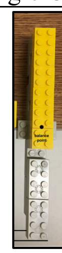
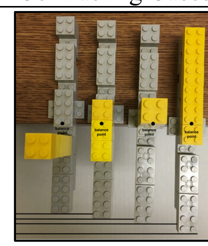
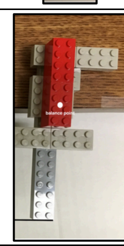
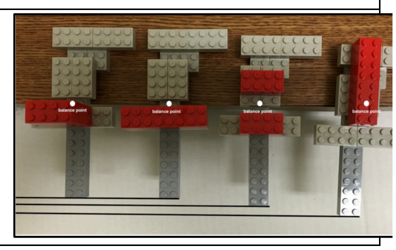
	Single Cases	Contrasting Cases
1st set		
2nd set		

Figure 3: Single Cases and Contrasting Cases

Reading The reading was a textbook-style passage that explicitly introduced the center-of-mass concept both qualitatively with illustrative, concrete examples and quantitatively, demonstrating a worked example that solved for the location of a center-of-mass of a group of objects. The reading constrained the discussion of center-of-mass to a single plane in the X dimension, which is relevant to the Lego-building task.

Measures

Near and Far Transfer Test The posttest contained 2 near and 2 far transfer items which differed in the relative transfer distance they traversed from the engineering design challenge (Perkins & Salomon, 1992). Near transfer items asked learners to apply explicitly taught COM concepts in novel situations that were not depicted in the design challenge. For

whereby contrasting cases provide an exploratory experience that prepares students to learn from later, explicit instruction.

example, in one item, participants were shown an image of two ducks of the same mass sitting on opposite ends of a see-saw and were asked to explain how they could move the see-saw up and down. Far transfer items asked participants to go beyond mere application by adapting and extending COM concepts in both novel ways and novel contexts that were not addressed in the design challenge. An example item asked learners to explain how a sculpture could defy gravity and still stay standing, for which they would need to consider the relationship of the COM over a structure's base, a novel concept. Written explanations were coded using a 0/.5/1 coding scheme for incorrect, partially correct, and fully correct answers. IRR across test items was acceptable, ranging from κ = .71 to .89. Item scores were averaged to compute near and far transfer subtest scores.

Performance Performance on the engineering challenge was measured by hang length. Hang length is how far the cantilever hung off the table, when pushed as far to the edge as it could go without falling. Hang Length was measured at the end of the pre, mid, and post-build periods.

Noticing Deep Structure We coded participants' written responses to worksheet prompts for evidence of noticing the deep structure of COM while they were designing their cantilevers and analyzing cases. The following pieces of data were coded: responses to design worksheet questions and the final rules of the cases activity sheet (for SC and CC only). Responses were coded on a 0/.5/1 scale corresponding to low/medium/high noticing of deep structure of COM. A 0-scoring response focused on a single feature (either mass or distance); .5 both features; 1 the multiplicative relationship of mass and distance. Inter-rater reliability was excellent on the noticing code, κ = .91.

Results

We tested for gender effects in all analyses and included gender as a factor only when significant. All post-hoc analyses use the Bonferroni correction.

Near and Far Transfer Test

To test our prediction that contrasting cases would enhance near transfer of center-of-mass concepts, we conducted a repeated-measures ANOVA with condition and gender as between-subjects factors, item type as a within-subjects factor, and scores on near and far transfer subtests as outcomes. There was an item type x condition interaction, $F(2, 59) = 3.86$, $p = .03$, $\eta_p^2 = .12$. Confirming our prediction, post-hoc tests revealed that on the near transfer subtest, the CC condition outperformed both SC and NC conditions, *p's* < .03, which did not differ significantly from one another, $p = .99$ (see Figure 4). However, there were no differences between conditions on far transfer performance, *p's* > .15. There was also a main effect of gender, indicating that males outperformed females, $F(1, 59) = 6.38$, $p = .01$, $\eta_p^2 = 0.10$.

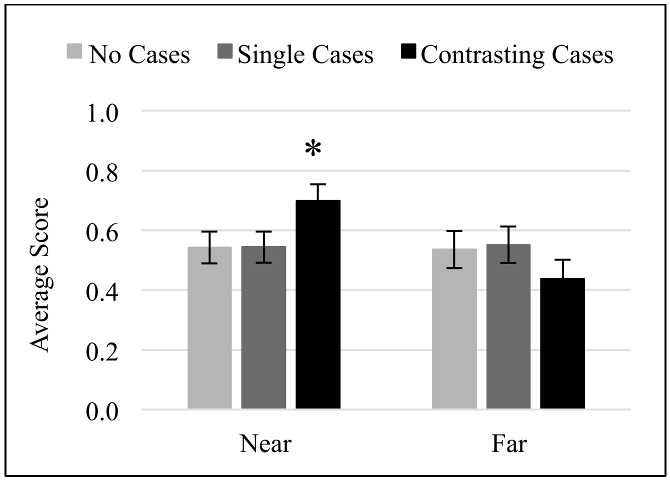


Figure 4: Near and Far Transfer Scores (Max = 1).

Building Performance

A repeated measures ANOVA with condition as a between-subject factors and time as a within-subjects factor, using pre, mid, and post hang lengths as outcomes found no interaction effect of condition x time, $p = .21$. However, there was a large, significant main effect of time, $F(2, 118) = 19.68$, $p < .001$, $\eta_p^2 = .25$, demonstrating gradual improvement from pre to mid-build, $p = .001$, which did not differ significantly from post-build, $p = .07$ (see Figure 5).

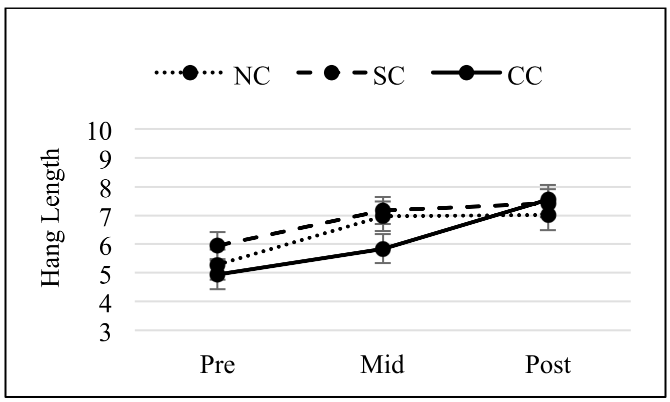


Figure 5: Performance on Lego Build Task Over Time

Noticing Deep Structures

To test for differences in noticing COM deep structure during designs, we conducted separate ordinal regressions using condition to predict mid and post-design noticing scores, while controlling for pre-design noticing. Neither regression produced a significant model, p's > .28, revealing that conditions did not differ in the level of deep structure they noticed in their cantilever designs. To test for condition differences in noticing COM deep structure during the cases activity (SC and CC conditions only), we conducted a similar ordinal regression, and once again, the model was not significant, $p = .54$, indicating similar levels of noticing from the cases in SC and CC conditions.

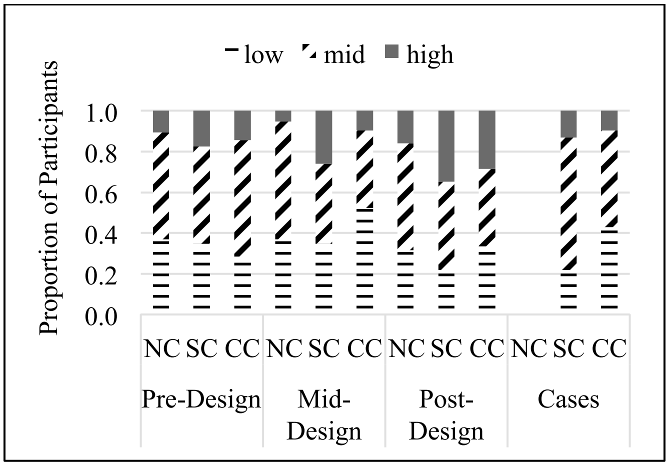


Figure 6: Noticing Deep COM Structures during Reflections

Surprisingly, the level of noticing did not vary much with time, though descriptively, participants noticed at a deeper level after the reading. Summing across all conditions, the percent of participants who noticed the structure of center-of-mass at the deepest level was pre = 14%, mid = 14%, post = 27%, and cases = 11% (SC and CC conditions only). It is also interesting to note the relatively low rate of noticing during the cases activity.

Relating Noticing, Performance, and Transfer

To explore the relationship between noticing and performance, we conducted a linear regression of final build performance, using pre-performance and average noticing scores (across mid and post-designs) as predictors. This model explained 19% of the variance in performance, $F(2, 60) = 7.20$, $p = .002$, with pre-performance as a significant predictor, $\beta = .27$, $t(60) = 2.09$, $p = .04$, and noticing as a marginally significant predictor, $\beta = .25$, $t(60) = 1.91$, $p = .06$. Variables for condition and their interactions were not significant when added to the model. So, regardless of condition, deeper noticing of center-of-mass was associated with better performance on the engineering design task.

We also explored the relationship between noticing, performance, and transfer outcomes. We conducted a linear regression to predict far transfer scores, using gender, final build performance, and average noticing score (across mid and post-designs) as predictors. The model explained 19% of the variance in far transfer scores, $F(3, 59) = 4.68$, $p = .005$. Noticing was the only significant predictor, $\beta = .28$, $t(59) = 2.25$, $p = .03$. Moreover, condition and interaction variables did not predict significant variance when added to the model. Thus, deeper noticing of center-of-mass structure was associated with greater transfer to far contexts, over and above performance on the engineering task, and regardless of condition. We ran the same analysis to predict near transfer scores, but found no significant predictors.

Discussion

This study explored the relative efficacy of contrasting cases, single cases, and no cases in supporting the transfer of learning from an engineering design activity to novel contexts. In line with our predictions, participants who reflected on contrasting cases in the midst of the engineering design task showed greater near transfer than those who reflected on single cases or no cases at all. However, these group differences did not hold up on the far transfer test, where all conditions performed similarly. Perhaps a larger dosage of instruction over more time is necessary to invoke transfer to remote contexts.

The cases manipulation had no impact on performance in the engineering design challenge. Participants across all conditions improved their performance over time. One might interpret this result to mean that participants were not connecting the cases to the building activity (yet another failure of transfer!). However, our explanation of these results is that participants were able to improve on the engineering design activity either through trial-and-error or by relying on the COM knowledge they were developing from the interspersed instruction. This is consistent with prior research, which finds that people can often tinker their way toward building successful engineering products without applying science content (Vattam & Kolodner, 2008).

Also, we had hypothesized that contrasting cases would facilitate transfer by enabling learners to notice deep scientific structures. However, we found no condition differences in deep structure noticing. In fact, descriptively (though not significantly) the group that reflected on single cases showed deeper noticing. It is possible that the single cases were treated as analogs, since the two individual cases were fairly similar. Though single cases were presented on two separate pages, participants may have compared them. It is also possible that the contrasting cases require deeper and longer processing on the part of participants. Perhaps a combination of analogous and contrasting cases, with prompts to engage deep processing of the cases, would be most effective at enhancing noticing.

In line with our predictions, level of noticing predicted far transfer. Moreover, we found a trend of noticing predicting task performance. More generally, these findings confirm perceptual accounts of the impact of perceptual processes on transfer and skilled performance, and this research extends these findings to the engineering context.

An interesting question that emerged is how the contrasting cases group was able to demonstrate greater near transfer without greater noticing. It may be that the contrasting cases helped learners develop some implicit form of noticing, which they transferred to near situations (Day & Goldstone, 2012). Future research could explore this possibility.

A main limitation of this work is the low number of participants and accompanying issues of low statistical power. Given this, we were only able to defect large effects. Additional studies with larger samples and additional populations are needed before the results can be generalized.

Another limitation is that without a condition that does not build, we cannot explore the contribution of the engineering design task in facilitating transfer. In the future, it would be interesting to conduct a 2x2 study in which learners either analyze contrasting cases or no cases, with and without the building activity. Future work could also attempt to replicate these findings in a longer intervention in a classroom setting to see (1) whether our integration of contrasting case and engineering activities would be effective in the real world, beyond the lab, and (2) whether a longer intervention would invoke far transfer.

Despite the need for additional research, the current study makes several contributions to the literatures on contrasting cases and science and engineering education. An extensive body of work has explored the role of comparison in facilitating transfer. This work adds to the emerging body of research on the role of contrasts in helping learners notice deep structures in learning and transfer contexts. Second, this work demonstrates an alternative route towards successful transfer, which can be an elusive outcome. Third, this work confirms the role of perceptual processes, such as noticing, in supporting transfer. Fourth, our findings have implications for the design of engineering tasks: adding contrasting cases to an engineering design activity can enhance the transfer of physics knowledge to novel (but near) contexts. While engineering tasks can lead students to focus too much on doing and not enough on relevant science content, embedding contrasting cases in the engineering activities may help learners recognize the science content in non-engineering situations.

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