UTILIZING CONTRASTING CASES TO TARGET SCIENCE REASONING AND CONTENT IN A DESIGN-FOR-SCIENCE UNIT

A quasi-experimental design to test the use of contrasting cases as an instructional tool to support science learning in a design-for-science classroom was conducted. Five eighth grade science sections from one teacher were assigned to one of two conditions, Contrasting Cases (N=54 students) or Sequential Cases (N=30 students). The influence of contrasting cases on domain-general science reasoning knowledge, domain-specific differentiated knowledge, and domain-specific content knowledge was investigated. The exposure to contrasting cases was effective only at increasing domain-general science reasoning. In addition, science reasoning was a significant predictor of content knowledge, but differentiated knowledge was not. Thus, the mediated effect of contrasting cases on content knowledge through reasoning knowledge, if it exists at all, was not strong enough to be observed in these data. Improvements to the implementation of contrasting cases in the unit, and in design-for-science curriculum in general, are considered.

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Introduction and Background

The goal of this research was to inform the effective implementation of a design-for-science unit (Leonard, 2005) to better understand the ways in which students can draw from multiple, case-specific experiences to form general science ideas. The theory of contrasting cases (Schwartz & Bransford, 1998) provided a framework for designing an instructional tool to support students' learning of abstract and general science ideas from the concrete and real-world experiences of an engineering design activity. The study context was a design-for-science unit implemented in a middle school science classroom to teach electricity concepts.

Learning science through design has been shown to be effective in a number of instances (e.g., Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004; Kolodner, Gray, & Fasse, 2003). Design units may be effective for learning abstract and general science ideas because they provide a concrete context to represent, manipulate, and revise ideas through the design of an artifact (Roth, 2001). In addition, design units may be particularly motivating and engaging to students as the real-world problems encourage students to utilize their own needs and solutions (Benenson, 2001).

Although the use of engineering design to teach science may have potential benefits, it also may add a layer of complexity that has the potential to obscure the core science concepts and processes that are the ultimate goal of the learning activities (Roth, Tobin, & Ritchie, 2001). For instance, students may get absorbed in the construction of their particular design to such an extent that they do not take the time to test ideas systematically or feel the need to generalize findings to other contexts. This may be related to students' understanding of the goals of their activity, since an engineering model of experimentation is likely to encourage a focus on producing a desired effect rather than understanding the causal relationships among variables (Schauble, Klopfer, & Raghavan, 1991). As a result, students engaging in engineering design activities may not effectively use their design experiences to construct science knowledge that generalizes beyond their particular design.

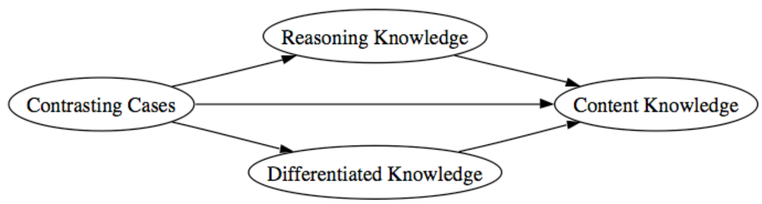
The learning theory underlying effective design-for-science curricula has been articulated in depth as an extension to case-based reasoning, such as in the Learning by Design™ (LBD) curriculum units (Kolodner, Camp et al., 2003). Although compare-and-contrast activities have been utilized as central component of the LBD curriculum units as a way to highlight some of the features and mechanisms that underlie the performances of different designs, their influence in those contexts has not been systematically explored. We saw contrasting cases as a promising instructional tool for focusing the efforts of students on particular ways of comparing different design cases. We felt that contrasting cases could help both in encouraging students to test their ideas in a way that is consistent with valid science reasoning and by highlighting particular content that is central to understanding the domain.

Contrasting cases are a method by which students are facilitated in creating knowledge that enables subsequent explanations to be better understood. Contrasting cases are effective when little prior knowledge of a domain exists, and thus serve to prepare students for future learning (Schwartz & Bransford, 1998; Schwartz & Martin, 2004). For example, when designing a general reliability score to assess different pitching machines, comparing sets of data on the machines that have different sample sizes can highlight the need to design a measure that can effectively account for different sample sizes (Schwartz & Martin, 2004). If students only compared data sets with a constant sample size, they may be likely to ignore that important feature in designing their metrics. Comparing cases side-by-side, as opposed to one after another, has been shown to increase transfer of ideas in other domains as well, such as in negotiation strategies (Gentner, Loewenstein, & Thompson, 2003).

According to Schwartz and Bransford (1998), the type of knowledge that is created by actively contrasting cases is referred to as *differentiated knowledge*, or the noticing of distinctions between different features, variables, and levels of variables. Schwartz and Bransford also provide evidence that the advantage of contrasting cases is only present when students are provided with a subsequent learning resource, such as a carefully-designed lecture, that helps students to form *explanatory knowledge*. The high level explanations provided in a learning resource are better understood after engaging in contrasting cases activities, but the contrasting cases are not sufficient by themselves.

In summary, contrasting cases are an effective way to help students attend to features of designs that are important and that may not be highlighted when analyzing only a single design case. This tool for learning maps nicely on to the use of engineering design activities for learning science. In addition to helping students attend to important variables that are central to the content of a science idea, contrasting cases may also help students to evaluate at a meta-level what makes a useful, valid contrast. This knowledge of how to reason with data, both in setting up the contrasts and drawing conclusions from them, is a central scientific practice that leads to more systematic tests of ideas and more generalizable knowledge. Thus, we hypothesized that not only would the impact of contrasting cases on increasing differentiated knowledge extend to a design-for-science context, but that the intervention would also be effective at modeling valid scientific reasoning, such as hypothetico-deductive reasoning (Lawson, 1978). Our prediction was that students exposed to contrasting cases throughout a design-for-science unit would have higher levels of domain-general science reasoning knowledge and domain-specific differentiated knowledge, and those higher levels of reasoning knowledge and differentiated knowledge would, in turn, be associated with higher levels of domain-specific content knowledge (see Figure 1). A two-group, quasi-experimental, pre-post design was used to test these predictions.

Figure 1: A schematic diagram of the hypothesized influence of contrasting cases.



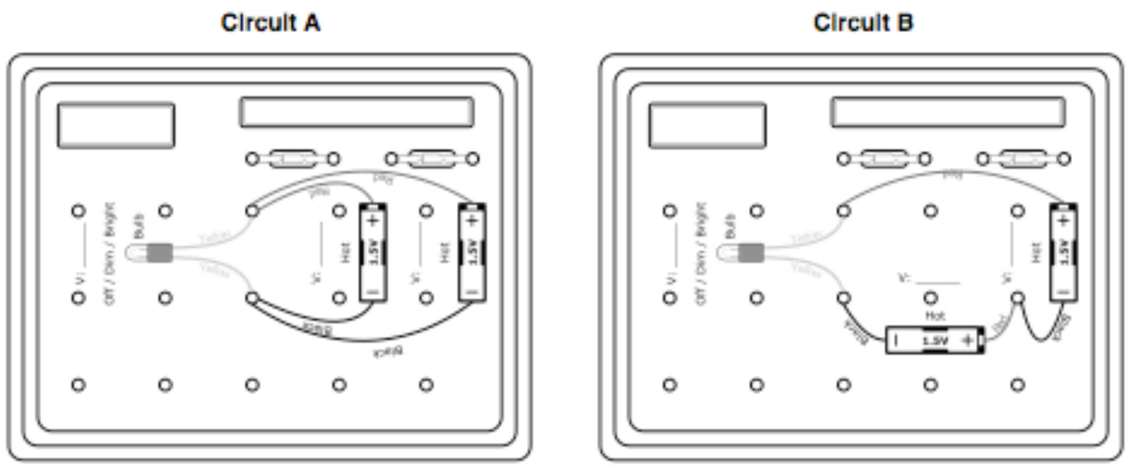
Design and Procedure

Curriculum

The context for this research was the *Electrical Alarm System* unit, which is a design-based learning unit (Mehalik, Doppelt, & Schunn, 2008) focusing on the teaching of core electricity concepts to eighth graders through the design of an alarm system that meets an everyday need (e.g., a locker alarm to inform me if someone breaks into my school locker). The unit is centered on the open-ended design and construction of a model of the alarm system in teams of three to four students. In addition to the open-ended aspect, the process is structured using an authentic engineering design framework (e.g., the generation and evaluation of alternative solutions, the presentation of in-progress designs, etc.), and the content is structured using a system decomposition approach, in which all alarm systems share common functional subsystems. More specifically, the unit was broken up into five sections: (1) introduction and open exploration, (2) power subsystem, (3) indicator subsystem, (4) detector subsystem, and (5) fine-tuning.

For each section, the student teams in both conditions were asked to complete an *open-ended case analysis* followed by a *scripted case analysis*. The open-ended case analysis required student teams to analyze two circuits of their own design that they found to be meaningful during their unguided team exploration. They filled out a worksheet in which they were asked to draw their circuits and then answer questions about them. The questions focused on distinguishing the *design* of the circuits (i.e., the arrangement of components and how the circuit was constructed) from their *behavior* (i.e., how the circuit as a whole and the individual components performed, did they turn on or get bright, etc.), and then on accounting for the impact of the design on producing the observed behavior using an explanation. The scripted cases were provided on a similar worksheet, except that the circuits had already been drawn and the student teams were expected to reproduce and analyze the circuits that were given. The scripted cases were specifically designed to highlight key ideas as well as model valid experimental tests when viewed as a contrasting pair. Figure 2 shows an example of a scripted contrasting case intended to highlight the different behavior that results from placing batteries in parallel versus in series with a bulb. Although both conditions received the open-ended cases worksheets followed by the scripted cases worksheets in each section, in the *Contrasting Cases* condition, the open-ended and scripted cases were presented on the worksheet page side-by-side and the accompanying questions explicitly asked students to compare and contrast the cases, including their design and their behavior. In the *Sequential Cases* condition, the same cases were separated on different pages and no explicit direction to compare or contrast was provided. After completing an open-ended and a scripted cases analysis, students then presented their findings to the class. Their presentations then served as the basis for whole class discussions around the science ideas related to core content of electricity. This routine of analyzing cases, presenting findings, and engaging in whole class discussions was repeated for each subsystem.

Figure 2: An example scripted contrasting case highlighting arrangement of the batters (parallel versus series) in a simple circuit.



Students were given a paper-based assessment before the beginning of the unit and the same assessment at the conclusion of the unit. The assessment included three distinct measures: (1) *domain-general science reasoning knowledge* (12 multiple-choice items), including the control-of-variables strategy and the drawing of appropriate conclusions given a set of data; (2) *domain-specific differentiated knowledge* (9 open-ended items), including the identification of relevant explanatory variables such as the arrangement, quantity and type of different components, and (3) *domain-specific electronics content knowledge* (41 multiple-choice items), focusing on patterns and relationships involving voltage, current, resistance, and parallel and series circuits. The Cronbach's alpha measure of internal consistency for the three measures at post-test, .73, .59, and .51 respectively, indicated that all three were reliable measures. The differentiated knowledge measure consisted of a set of comparisons between two circuits in which students were asked to list the differences between them. A point was scored for each relevant difference that was explicitly listed. Because in previous work with this measure we obtained over 90% agreement between raters on each difference, only one rater was used for these data.

Participants

This study was conducted in a mid-size, urban public school. One teacher participated in the research. This was her third time teaching this design unit. All five sections of her eighth grade science class participated. Two of the sections were assigned to the *Sequential Cases* condition and the other three were assigned to the *Contrasting Cases* condition. The assignment of classroom sections to conditions was done in order to balance the demographic characteristics of the students in each condition. The setting was a challenging environment—the demographics of the participating students included 79% of the students from a minority ethnic background, 65% from a low socio-economic background, defined as qualifying for government subsidized free or reduced lunch, and 30% designated through an IEP as non-gifted special education students.

There were a total of 54 students in the two *Sequential Cases* sections and 75 students in the three *Contrasting Cases* sections. As a result of the challenging conditions, we were unable to collect all the data because of excessive absences, transfers between schools, suspensions, etc. In addition, one student's data was removed because it was an extreme outlier on the pre-test (> 3 x Interquartile Range). The final total of complete and valid data collected was from N=30 in the *Sequential Cases* condition and N=54 in the *Contrasting Cases* condition. See Table 1 for a summary of the demographic characteristics of the students in each condition.

Table 1: The demographic characteristics of the students in each condition.

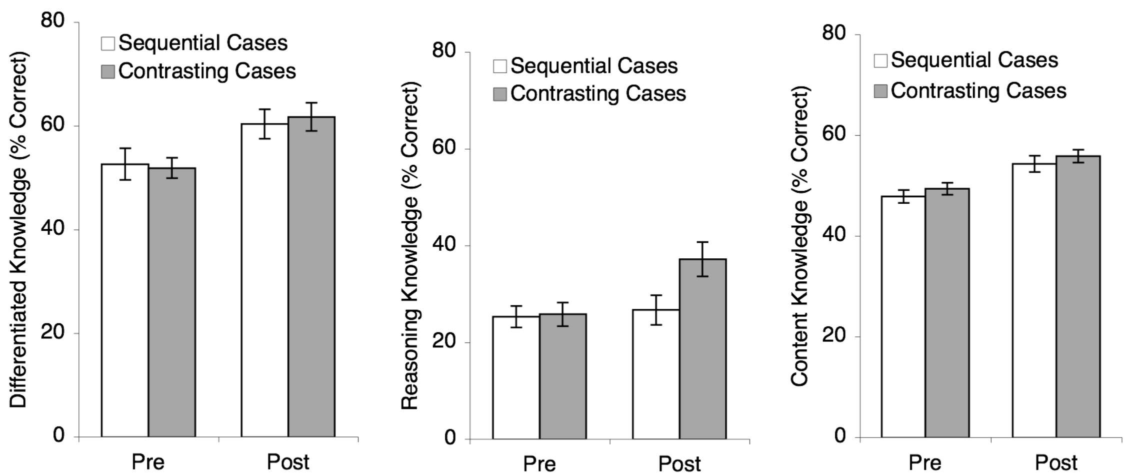
	Female	Subsidized Lunch	African-American	Special Ed
Sequential Cases (N=30)	50%	40%	80%	23%
Contrasting Cases (N=54)	48%	80%	78%	33%

Analyses and Findings

Pre-to-Post Improvement

In order to test the prediction that using contrasting cases would increase science learning in a design unit, we looked for differences between conditions on the three post-test measures. Figure 3 provides a summary of the pre- and post-test scores on each measure for each condition. The post-test domain-general science reasoning knowledge (RK), domain-specific electricity differentiated knowledge (DK), and domain-specific electricity content knowledge (CK) scores were each used as a dependent measure, with condition as the independent variable. Even though the pre-test scores of the two conditions were not significantly different on any of the three dependent measures, we used an ANCOVA to account for some of the variability in pre-test scores and to increase statistical power. The analysis revealed that on all three measures, students as a whole improved from pre- to post-test from participating in the engineering design unit. In addition, there was a significant main effect of condition on reasoning knowledge ($F_{1,81}$ = 5.35, $p < .05$), such that the students in the *Contrasting Cases* condition learned more science reasoning than the students in the *Sequential Cases* condition. There was not a significant effect of condition on differentiated knowledge ($F_{1,81}$ = .18, p = .67) or on content knowledge ($F_{1,81}$ = .18, p = .68), indicating that both groups of students performed equally well on those domain-specific content measures. Thus, it appears that exposure to contrasting cases was only effective at increasing domain-general science reasoning knowledge, and the intervention was not effective at impacting the domain-specific measures.

Figure 3: Mean pre- and post-test scores (+SE) on the three science knowledge measures separated by condition, Sequential Cases (n = 30) and Contrasting Cases (n = 54).



Influence of Reasoning and Differentiated Knowledge on Content Knowledge

Independent of whether the use of contrasting cases impacted the different knowledge measures, we can test whether the theory explains other patterns in the data. Our prediction was that higher levels of reasoning knowledge and differentiated knowledge together would predict higher levels of content knowledge. In order to test this prediction, we conducted a multiple regression analysis with the post content knowledge measure as the outcome, pre content knowledge as a controlling variable, and post reasoning knowledge, post differentiated knowledge and their interaction as predictors. The regression model was a fair fit to the data (R^2_{adj} = .37), but the overall relationship was significant ($F_{4,79}$ = 12.98, $p < .001$). In the model, reasoning knowledge (b = 1.06, t_{79} = 2.06, $p < .05$) was positively associated with content knowledge indicating that better science reasoning does lead to increased knowledge of the content. Differentiated knowledge as a main effect (b = .61, t_{79} = 1.46, p = .15) and the interaction between reasoning knowledge and differentiated knowledge (b = -.07, t_{79} = -.90, p = .37) were not significant predictors. From this analysis, it seems that the theory is only partially supported by the data, in that a strong association between differentiated knowledge and content knowledge was not observed.

Conclusions and Implications

Our findings support the claim that utilizing contrasting cases as an instructional tool can enhance a design-based science unit, but not to the extent that we had hoped. We observed that students who were exposed to the contrasting cases were able to acquire better reasoning knowledge, which extends our previous work in targeting domain-general science reasoning knowledge through engineering design units (Silk, Schunn, & Strand Cary, 2007). On the other hand, the gains in reasoning knowledge from using contrasting cases did not appear to translate into gains in content knowledge, even though reasoning knowledge was a significant predictor of content knowledge overall. This may be due to the nature of the relationship between contrasting cases as an instructional intervention and content knowledge as a learning outcome as being mediated by reasoning knowledge, so that the relationship is not a direct one. In other words, contrasting cases may only be effective at helping students to develop content knowledge when those students have already acquired effective science reasoning skills. In addition, because the relationship between contrasting cases and reasoning knowledge ($r = .21$) and the relationship between reasoning knowledge and content knowledge ($r = .60$) were not especially strong, the mediated effect was necessarily weaker and thus may not have been able to be observed in these data. A larger sample may have produced effects large enough to detect these relationships. More likely, though, is that a higher-quality implementation of contrasting cases as an instructional tool could have increased the strength of the effects of reasoning knowledge and content knowledge, as well as the relationships between them. For example, we did not systematically analyze the quality of the whole-class discussions so we are not sure the extent to which students were provided with sound explanations of the science ideas after having differentiated important features of their designs in their case analyses. Furthermore, it is possible that students in the *Sequential Cases* conditions also engaged in the direct comparisons and contrasts between circuits since the two circuits they analyzed, although not on the same page, were given to the groups at the same time. In summary, it appears that the theory of contrasting cases was not supported by this data, but that may have been due to the quality of the intervention rather than the value of contrasting cases more generally. We hope to continue work in the future that will help us to understand better in what ways the contrasting cases may be implemented in a higher-quality manner, both to enhance science reasoning and differentiated knowledge.

We still have much to learn about structuring learning tasks in design-for-science environments such that students are able to come to valid and sound conclusions that increase and create coherence within their overall understanding of the domain. As in all real-world science domains, the cases about which students observe are often difficult to interpret, even if effective science reasoning strategies are applied and so the process of constructing general understandings is not straightforward. Students need continued, appropriate supports in making sense of and explaining their observations in a way that is consistent with canonical science views. More careful exploration of the types of interpretations students made in analyzing their cases and the explanations provided by the teacher in the subsequent whole class discussions may illuminate reasons why many challenges still remain and highlight opportunities to revise our instructional interventions. Our intention is to continue to work toward identifying examples of effective classroom interventions that facilitate students in thinking carefully about how the concrete cases that they consider in the process of designing engineering solutions to particular problems can be generalized to more abstract knowledge of science ideas that apply across many different cases and contexts.

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