Learning and Transfer from an Engineering Design Task:

The Roles of Goals, Contrasting Cases, and Focusing on Deep Structure

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ABSTRACT

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As maker spaces, engineering design curricula, and other hands-on active learning tasks become more popular in science classrooms, it is important to consider what students are intended to take away from these tasks. Many teachers use engineering design tasks as a means of teaching students more general science principles. However, few studies have explored exactly how the design of these activities can support more generalized student learning and transfer. Specifically, research has yet to sufficiently investigate the effects of task design components on the learning and transfer processes that can occur during these kinds of tasks.

This dissertation explores how various task manipulations and focusing processes affect how well students can learn and transfers science concepts from an engineering design task. I hypothesized that learning goals that focus students on the deep structure of the problem, and contrasting cases that help students notice that deep structure, would aid learning and transfer. In two experimental studies, students were given an engineering design task. The first study was a 2x2 between subjects design where goal where goal (outcome or learning) and reflection (on contrasting cases or the engineering design process) were manipulated. A subsequent second study then gave all students contrasting cases to reflect on, and only the goal manipulation was manipulated. Results showed that learning goals improved student performance on a transfer task that required students to apply the deep structure to a different engineering design task. In the second study, learning goals improved student performance on a transfer test. Transfer performance in both studies was predicted by the ability to notice the deep structure during the

reflection on contrasting cases, even though noticing this structure did not differ by goal condition. Students with a learning goal valued the learning resources they were given more during the engineering design activity, and this perceived value of resources was linked to greater learning.

A qualitative case study analysis was then conducted using video data from the second study. This case study investigated noticing processes during the building process, partner dialogue, and resource use. This analysis showed how high transfer pairs were better able to focus on the deep structure of the problem. Results suggest that what students noticed didn't differ much between the various pairs. However, high transfer pairs were better able to focus on the deep structure through establishing a joint understanding of the deep structure, sustaining concentration on that deep structure during the cases reflection, referencing resources to identify features to test, and then systematically testing those features to identify their relevance. These processes are discussed in relation to how they differ in low transfer pairs.

This dissertation consists of four chapters: an intro, two standalone journal articles, and a conclusion. The first chapter provides a conceptual framing for the two journal articles, and discusses the findings from these articles in conversation. The second chapter describes the two empirical studies investigating how task goals and contrasting cases affect learning, and transfer from an engineering design task. The third chapter describes the comparative case study of how mechanisms of focusing on the deep structure differ between high and low transfer pairs. Finally, the fourth conclusion chapter discusses the implications of the work from both of these papers.

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CHAPTER 1: INTRODUCTION

With the modern surplus of job opportunities in engineering, there is a growing interest in engaging K-12 students in engineering education. For example, Next Generation Science Standards are calling for K-12 students to gain proficiency in engineering design practices in addition to learning science content (NGSS Lead States, 2013). Alongside the introduction of these standards, makerspaces (Halverson & Sheridan, 2014) and FabLabs (e.g., Jona, Penney, & Stevens, 2015) have been popping up all around the country with the intention of organically engaging students in science and engineering practices. Simultaneously, educational researchers have designed rigorous engineering design curricula such as Learning by Design (LBD; Kolodner, Crismond, Gray, Holbrook & Puntambekar, 1998), Design for Science (Silk, Schunn & Cary, 2008), Engineering is Elementary (Lachapelle & Cunningham, 2007) and others, which allow students to participate in engineering design practices, while also developing competencies in math and science content.

But simply having students do engineering design projects does not guarantee students will learn science principles from these activities (Petrosino, 1998; Barron et al., 1998).

Although engineering design curricula seem to be very effective, successful application of these curricula for the sake of teaching conceptual science can be difficult. Students can be distracted by the nitty gritty of construction and fail to effectively reflect on the associated science concepts that could aid their designs (e.g., Gertzman & Kolodner, 1996; Hmelo et al., 2000; Kanter, 2010; Roth, Tobin, & Ritchie, 2001; Silk, Schunn & Cary, 2007; Vattam & Kolodner, 2008, etc.). This lack of reflection can in turn hurt a student’s ability to learn appropriate science concepts from the engineering design activity (Worsley & Blikstein, 2014). Furthermore, even when students do think about math and science concepts, they may fail to employ these concepts into their design process during the learning task (Berland, Martin, Ko et al., 2013). Ultimately, this prior research suggests that engineering design activities are hard to implement effectively, especially if they are being used with the intention of teaching students science content.

In response to this issue, I suggest two key ways to encourage students to learn science concepts and applying those concepts to their work. First, I propose that learning task goals are essential to focus student attention on learning the deep structure (core science concepts) of the task instead of constructing. Secondly, I propose that having students reflect on contrasting cases will help them notice the deep structure of the task which can help students both learn and transfer that core science content. Together, learning goals and contrasting cases could improve students' ability to notice and focus on the deep structure of the task, which in turn may improve learning, performance, and transfer.

Learning goals, are goals that focus students on learning the core content of the task, instead of creating some task outcome. These kinds of goals have been shown to improve student strategies (Gardner et al., 2016; Winthers & Latham, 1996), exploration of the problem space (Schauble, Klopfer, & Raghavan, 1991), and attention to learning materials (Rothkopf & Billington, 1979). As a result, learning goals can improve student learning (Miller, Lehman & Koedinger, 1999), as well as task performance and transfer (Schunk & Swartz, 1993).

Meanwhile, contrasting cases are examples that systematically vary on key features, in order to help students notice the deep structure of a problem. Work has shown that contrasting cases not only aid deep structure noticing, but also improve transfer (Aleven et al., 2017; Bransford, Franks, Vye, & Sherwood, 1989; Chase, Harpstead, & Aleven, 2017; Roll, Aleven, & Koedinger, 2011; Schwartz, Chase, Oppezzo, Chin, 2011; Shemwell, Chase, & Schwartz, 2015).

I propose that task goals and cognitive scaffolds interact to improve student learning and transfer. Goals affect how much students pay attention to learning materials (e.g. Ames & Archer, 1988; Locke & Bryan, 1969; Rothkopf and Billington 1979) and contrasting cases affect how students notice the deep structure. Both of these mechanisms are necessary for transfer. Without goals, students are not paying attention to cognitive scaffolds, and more interesting, yet irrelevant, problem solving strategies or tools may be used instead. Without cognitive scaffolds, students may want to engage in helpful learning strategies, but suffer from an issue most novices have of not knowing what features of a problem are relevant (Chi, Feltovich, & Glaser, 1981). In this way, I propose that students need to have both effective learning goals and proper cognitive scaffolds to be able to learn and transfer most effectively.

The next two chapters explore the processes by which learning goals, contrasting cases, noticing deep structure, and focusing on deep structure affect learning, performance and transfer. The chapters describe the work done on two studies where students were given an engineering design task created to teach concepts about center of mass. Chapter 2 discusses the effects of learning goals and contrasting cases on students during this activity. Chapter 3 discusses a case study that investigated how high transfer pairs and two low transfer pairs notice and subsequently focus on the deep structure of the task. Results from these two chapters highlighted the importance of noticing and focusing on the deep structure of the problem, students building in a systematic way, and using resources wisely in order to best support learning and transfer.

Both chapters highlight the importance of noticing and focusing on the deep structure of the problem. Quantitative work showed that noticing the deep structure during the contrasting cases reflection aided student learning and transfer. The case study then showed that even when high and low transfer pairs were both able to notice the deep structure of the problem, only the high transfer pairs were able to focus on this deep structure. As a result, high transfer pairs were better able to determine and the importance of the deep structure when other features and attributes of the task were competing for those students' attention. Together, these studies highlight that both noticing and focusing on deep structure are key processes for transfer.

Work from the quantitative paper and case study also signify the importance of building effectively. The quantitative paper showed in one study that task performance was predictive of subsequent student transfer performance. The case study showed this process in more detail. High transfer pairs built their structures in a more systematic way, by making small changes and testing the efficacy of each of these changes. As a result, high transfer pairs were able to build longer structures and determine which features and structures of the problem were relevant or irrelevant. Taken together, these results suggest that students who effectively use the building process to determine the relevant features of the problem both build longer structures, and are better able to focus on the deep structure. These processes may explain why students who had better structures also had higher transfer scores.

Finally, both chapters highlight the importance of resources. The quantitative study showed that students who were given learning goals perceived the resources they had to be more helpful. This perception in turn was associated with higher learning scores. In the case study, high transfer pairs viewed the resources more often throughout their construction time. Furthermore, when looking at the resources, high transfer pairs identified features that they could test in their build. In this way, high transfer pairs used the resources to aid their building process, which in turn helped them focus on the deep structure of the problem. So, learning goals may have lead students to find more value in these resources, and students who used these resources wisely had more scaffolding to learn from the building activity.

This work has implications for how to better support learning and transfer from engineering design tasks. First, results suggests that engineering design activities should include scaffolds that help students both notice, and focus on the deep structure of the task over time. Secondly, this work suggests that even though learning goals do not necessarily aid deep structure noticing, they do support some processes for transfer. Future work should investigate the mechanisms by which learning goals are aiding transfer. Thirdly, findings indicate that students should be supported in their building process. Although much research has covered the importance of controlled testing for science inquiry learning (Boudreaux, Shaffer, Heron, & McDermott, 2008; Chen & Klahr, 1999; DeBoer, 1991; Duschl, 1990), little work if any has considered the importance of this process on helping students focus on the deep structure of a problem. Finally, this work indicates that learning goals might be a key way to help students find more value in learning resources. In turn, students should be encouraged to engage with resources more often and more meaningfully during engineering design tasks, as these resources can aid focus on the deep structure or inform building and testing processes.

Ultimately, I argue that learning goals and focusing on deep structure are two important components of effective transfer from engineering design tasks. Using a mixed-methods approach, which leverages both quantitative and case study research, I was able to determine a nuanced account of how these two mechanisms affect transfer. I hope in turn that this work will inform both literature on how transfer happens as well as how to best support student transfer from engineering design tasks.

CHAPTER 2: EXPERIMENTAL INVESTIGATION

How Learning Goals and Contrasting Cases Affect Learning and Transfer from an Engineering Design Task

Abstract

Engineering design tasks are a popular way of teaching science, but these activities can lead students to focus more on the success of their construction rather than learning the science content that could help them solve the problem. This focus on task outcomes can hurt students' ability to learn and transfer science principles from these kinds of tasks. Two empirical studies investigate how goals and contrasting cases affect learning and transfer. Students were told to build a cantilever out of Legos, which involved understanding and applying center of mass concepts. In study 1, 86 high school students were given either a learning goal, to identify the deep structure of the problem, or an outcome goal—to build a successful cantilever. Students were also given either contrasting cases, which helped students notice the deep structure, or they were told to reflect on the design process. Results showed that learning goals and contrasting cases affected performance on a transfer engineering design task, while noticing the deep structure of the problem improved learning and transfer posttest performance. In study 2, a new set of 78 high school students received contrasting cases, and the goal manipulation was reinforced. Results showed that learning goals improved both transfer performance and how much students valued learning resources. Perceived value of resources improved learning, and noticing the deep structure improved transfer. I then discuss how learning goals can be used to support transfer and the importance of deep structure noticing for transfer as implications for the transfer and engineering design task literatures.

Introduction

Learning from Engineering Tasks

For decades, scholars and teachers have been interested in how to design hands-on engineering tasks to effectively teach students core science concepts (e.g. Barron et al., 1998; Kolodner et al. 2003; Silk et al., 2008; Worsley & Blikstein, 2014). However, just having students participate in engineering design activities is not sufficient to teach students science. For example, work by Petrosino (1998) illustrated that simply having students make and launch rockets did little in the way of teaching them science or engineering concepts. Subsequently, engineering design tasks and curricula have been developed to incorporate an assortment of instructional scaffolds meant to aid learning and transfer. These scaffolds include peer feedback (Adams, Turns, & Atman, 2003; Berland, Martin, Ko et al., 2003; Cunningham, 2009; Fortus, Dershimer, Krajcik, Marx, & MamlokNaaman, 2004; Gero, Jiang, & Williams, 2013), multiple challenges that allow students to abstract principles (Berland, Martin, Ko et al., 2003; Fortus et al., 2004; Silk et al., 2009), specific opportunities for reflection (Berland, Martin, Ko et al., 2003; Fortus et al., 2004; Gero et al., 2013; Schunn, 2011; Silk et al., 2009; Svarovsky & Shaffer, 2007), concept focused brainstorming (Worsley & Blikstein, 2014), activities that directly address common misconceptions (Schnittka & Bell, 2011), and software supported design case comparisons (Svarovsky & Shaffer, 2007; Vattam & Kolodner, 2008).

These curricular scaffolds are meant to direct student cognition during the design task so that students can then learn better from some later instruction in the form of readings, lectures, class discussion, and individual tutoring (e.g., Fortus et al., 2004; Kanter, 2010; Kolodner et al., 2003; Silk, et al., 2009, etc.). This formal instruction is intended to ensure that students understand the science content that can inform their design. It is typically given, “just in time”, or when it is assumed that the student will be most amenable to using that knowledge to inform their design process, such as to push the student beyond an impasse. The assumption is, that once students realize that they can't fulfill an engineering design challenge with their limited prior knowledge, students will expand their science knowledge through reading, lecture, or discussion, and then effectively implement what they have learned in their design.

However, despite all this good intention, there are many reasons why students fail to effectively learn and transfer from these kinds of tasks. First, successful design curricula often bestow the role of scaffolding students on the instructor (Kolodner, Gray & Fasse, 2003; Kanter, 2010) or activities that can take students weeks or even months to master (Kolodner et al., 2003; Kolodner, Gray & Fasse, 2003). However, non-expert teachers may allow students too much time for messing about with design task materials and too little time for activities that help students abstract the core science principles of the task (Gertzman & Kolodner, 1996; Hmelo, Holton, & Kolodner, 2000). As a result, engineering design tasks often turn into "arts and crafts" activities (Holbrook & Kolodner, 2000) where students focus solely on making their construction, and fail to deeply reflect on associated science concepts (Gertzman & Kolodner, 1996; Hmelo et al., 2000; Kanter, 2010; Roth, Tobin, & Ritchie, 2001; Silk, Schunn & Cary, 2007; Vattam & Kolodner, 2008, etc.). This lack of reflection can hurt a student's ability to learn appropriate science concepts from the engineering design activity (Worsley & Blikstein, 2014).

Learning and transfer failures may also occur from students failing to effectively use learning resources provided to them. Even when cognitive scaffolding and direct instruction are available to students, they don't necessarily use or value them. Although students often recognize how canonical science knowledge could relate to their designs, they can be hesitant to use it (Berland, Martin, Ko et al., 2013). Instead of using learning resources that teach core science knowledge, novice student designers often end up using trial-and-error to guide their design process (e.g. Ahmed, Wallace, & Blessing, 2003; Berland, Martin, Benton et al., 2013; Berland, Martin, Ko et al., 2013; Kolodner et al., 2003).

The question then becomes how to encourage students to engage with learning resources and cognitive scaffolds so that they can learn effectively from engineering design activities, without relying on the presence of an expert teacher to implement the task.

Learning & Outcome Task Goals

One key way to focus student attention on the core principles of the task, rather than the construction process itself, is by setting appropriate goals for students. This idea is not new. In a paper from 1998, Barron and colleagues noted that setting "learning appropriate goals" is an essential component of any project-based learning curriculum that intends for students to develop science knowledge. The authors discuss how during engineering designs tasks, students typically focus on the outcome of the task, such as whether or not their construction is successful. However, to get students to think about learning and applying science concepts to their designs, activities need task goals that focus student attention on learning instead of constructing.

Learning goals may therefore be a key means to ensure student transfer from engineering design tasks. For the purpose of this paper, "learning goals" are defined as goals that focus students on the learning content of the task. In this case, the learning goal is meant to direct students to think deeply about the science concepts that underlie the task. Contrast this with "outcome goals", which focus students on their performance on the task itself. These definitions are in line with the goal setting literature (e.g., Locke & Latham, 2002), or the engineering versus science goals literature (e.g. Schauble, Klopfer, & Raghaven, 1991), both of which focus on how task goals can focus students on either appropriate learning processes or performance.

It is important to note however that the term “learning goal” has been used in the literature to define many different constructs. Learning goals have been used to focus students on learning objectives (Rothkopf & Billington, 1979), learing strategies (e.g. Gardner et al., 2016), learning processes (e.g. Latham & Brown, 2006; Schunk & Swartz, 1993), or standards of achievement (e.g., Elliot & Harackiewicz, 1994). As such, using the term “learning goal” might evoke work on mastery versus performance *achievement* goals. However, in this literature, mastery goals are about focusing students on showing improvements in their competence, based on some task standard, such as simply showing improvement on a task from a prior assessment (Elliot & Thrash, 2001, p. 141). Contrast this with my definition of learning goals, which focus students on what content they should be learning from the task. In turn, the achievement goals literature defines performance goals as goals that focus students on demonstrating competence in relationship to some normative standard, such as out-performing their peers (Elliot & Thrash, 2001, p. 141). Contrast this with outcome goals, which focus students on what their product should be by the end of the task. In this way, the achievement goal literature focuses more on what the standards of competence are (self versus other) while the learning versus outcome goal literature is more about what the content of the task is.

In contrast, the learning and outcome goals discussed in this paper come from the goal setting literature (e.g. Locke & Latham, 2002; Locke & Latham, 1990; Locke, Shaw, Saari, & Latham, 1981). In this literature, learning goals are defined as, goals that focus on acquiring information, ideas, or strategies to accomplish a task. In contrast, outcome goals focus on performance on the task itself. Outside of goal setting literature, other work has employing these same general definitions, uses different names for these constructs. Other names include path goals versus standard goals (Miller, Lehman & Koedinger, 1999), process goals versus product goals (Shunk & Swartz, 1993), and engineering goals versus science goals (Schauble, Klopfer, & Raghaven, 1991). This paper uses Locke & Latham's (2002) terms learning versus outcome goals, because they more adequately describe the purpose of the task. An activity with a learning goal has the intention of making students learn some content, while an outcome goal has the intention of making students produce some outcome.

Learning goals may be good for engineering science activities, because they can direct student attention towards the underlying science content of the task. In contrast, outcome goals simply focus students on performing well on the task. Engineering tasks are particularly at risk for focusing students on outcome goals, since most engineering tasks are framed as outcome goals. For example, a common engineering design task goal might be to build the highest structure possible that will withstand an earthquake test (Apedoe & Schunn, 2012), or to construct a working water purification device (Riskowski, Todd, Wee, Dark, & Harbor, 2009). These outcome goals may lead students to believe that producing the desired outcome is the sole purpose of the task, rather than a means to learn some science content.

Learning goals may improve student learning by affecting how students work through problems. For example, a study by Winters and Latham (1996) found that students who were given learning goals not only performed better, but also used more effective strategies on a complex task than students who were just urged to do their best. Other work suggests that learning goals improve student attention to learning materials (Rothkopf & Billington, 1979). Similarly, work by Schauble, Klopfer, and Raghavan (1991) has shown that how tasks are framed affects whether students take on an engineering model or a science model of experimentation. Students who take on an engineering model tend to focus on outcomes, while students who take on a science model focused on determining the structural relationships between variables of the problem. In this work, students who took on the science model explored the problem space more, and made more appropriate conclusions based on their results.

As a result of directing students to use more appropriate learning processes, goals that focus students on thinking about the deep structure of the given academic task tend to improve learning more than goals that focus students on creating some desired outcome. Work has shown that learning goals that focus students on the core science principles of a game improve learning more than a task goal that focus students on an outcome, like performing well in the game (Miller, Lehman & Koedinger, 1999). Work in the domain of writing has also shown that goals that focus students on the deep structure of a task both performed and transferred more than students who were given outcome goals (Shunk & Swartz, 1993).

In this way, work across several different academic domains shows that students who take on a learning goal, which focuses them on the learning content of the task, both perform better and employ better learning strategies than students who take on an outcome goal. In turn, this suggests that for students to learn science content from engineering design activities, they need to be driven by learning goals, instead of goals that focus them on the outcome of the task.

Transfer & Noticing

However learning science content is not the only objective of engineering design tasks. Ideally, students should also be able to transfer what they have learned. If the intention is for students to learn science principles from some form of direct instruction and apply that knowledge to their designs, then students need to be able to transfer knowledge between those two contexts effectively. Furthermore, students should ideally finish these tasks with an ability to apply learned principles appropriately to other problems. Therefore, for students to be truly successful in these tasks, they must be designed to support transfer processes.

One way to support transfer may be by helping students notice the deep structure of the task. Some scholars argue that successful transfer is dependent on the ability to notice a deep structure as invariant across contexts, and to know how to act in accordance with the presence of that deep structure (Greeno, Moore, & Smith, 1993; Lobato, Rhodehamel, & Hohensee, 2012). In turn, perceptual theorists claim that exploring the problem space effectively helps students identify what to notice, so that students can use that improved perception to perform better on tasks that have the same deep structure (Pick, 1992). However, there is not a lot of empirical work connecting deep structure noticing and transfer (but see Schwartz, Chase, Oppezzo, & Chin, 2011), especially during complex, hands-on learning activities. Although there has been some work on transfer from engineering design tasks (Kolodner, Gray, & Fasse, 2003), it has not considered the role that noticing deep structure has on students' ability to transfer.

I hypothesize that noticing the deep structure (in this case the relationships between variables of the core science content that underlies the task) is imperative for students to transfer from engineering design tasks, and that learning goals may support this noticing process. Learning goals that focus students on learning the core science principle should improve noticing the deep structure and in turn improve transfer. Work already suggests that learning goals improve the quality of student exploration of the problem space during inquiry science tasks (Schauble, Klopfer, & Raghavan, 1991). However, I do not know of any work that has specifically measured the effect of learning goals on students' ability to notice the deep structure of a problem, even though work does suggest that learning goals improve transfer more than outcome goals (Schunk & Swartz, 1993).

In addition to learning goals, contrasting cases may help students notice the deep structure of the task. Contrasting cases are examples that differ on key features, to make certain variables or relationships more salient to learners (Bransford & Schwartz, 1999). For example, tasting glasses of wine side by side would make it easier to notice differences in each wine's flavor profile. Work on contrasting cases in instructional activities has shown that cases that differ on key features can aid students' ability to notice the deep structure of a problem, which in turn can improve transfer (Aleven et al., 2017; Bransford, Franks, Vye, & Sherwood, 1989; Chase, Harpstead, & Aleven, 2017; Roll, Aleven, & Koedinger, 2011; Schwartz et al., 2011; Shemwell, Chase, & Schwartz, 2015). However, there has not been much empirical work on the effect of contrasting cases on transfer from engineering design activities (but see Silk & Schunn, 2008).

In turn, learning goals and contrasting cases may interact to support student transfer. For one, goals affect how much students pay attention to learning materials (e.g. Ames & Archer, 1988; Locke & Bryan, 1969; Rothkopf and Billington 1979) and contrasting cases affect deep structure noticing. Both of these mechanisms are necessary for transfer. Without learning goals, students may not pay due attention to the cases, relying instead on other problem solving strategies like copying or trial-and-error. Without contrasting cases, even with good intention, students may struggle to notice the deep structure. Work has shown that novices struggle to determine which features of a problem are relevant (Chi, Feltovich, & Glaser, 1981). Furthermore, cases typically require deep processing. For example, work suggests that processes that aid deeper processing, like self-explanation, improve the efficacy of contrasting cases (Sidney, Hattikudur, & Alibali, 2015). Learning goals may encourage students to engage in that deep processing. Finally, most instructional activities that use contrasting cases give students a learning goal, such as to come up with a rule, pattern, or principle that is true for all cases (e.g. Bransford & Schwartz, 1999; Kapur, 2008; Schwartz et al., 2011). By asking students to create a rule, students are being asked to focus on that deep structure. However, I do not know of any work that uses contrasting cases for transfer and gives students an outcome task goal. Most work on contrasting cases gives students a learning goal that helps students focus on relationships between the cases. Therefore, I propose that students need to have a learning goal to use contrasting cases most effectively.

Other Transfer Processes. Aside from the effect of goals and contrasting cases, the building component of the task may also affect transfer. Implementing science principles into the build may be one way for students to practice transfer during the task, which might in turn aid student transfer out of the task. Qualitative research from Chapter 3 of this dissertation suggests that students who transfer better systematically integrate deep features and the deep structure into their build. This chapter investigates if building performance is associated with higher overall transfer test scores.

Finally, learning goals may affect how students use resources. Research suggests that goals affect student attention to learning materials (e.g. Ames & Archer, 1988; Locke & Bryan, 1969; Rothkopf and Billington 1979). Findings from Chapter 3 of this dissertation also suggest that students who transfer better use resources more often and more strategically throughout the task. Therefore, the present paper aims to look at how goals affect resource use, and subsequent transfer.

The Present Research

This work investigates how learning goals and contrasting cases interact to affect student learning and transfer from an engineering design task. To explore this relationship two studies were run. In both studies, students were given an engineering design task to build a cantilever out of Legos. Success on this task involved knowledge and application of center of mass concepts. In the first study, students were given a learning goal or an outcome goal. Contrasting case use was also manipulated, such that only half of students were given contrasting cases that highlighted the deep structure of the problem (center of mass concepts). In the second study, all students received cases, and only goals were manipulated across conditions. Both studies were driven by four main research questions. How do goals and contrasting cases affect student performance? How do goals and contrasting cases affect learning? How do goals and contrasting cases affect transfer? And finally, how do goals and contrasting cases affect processes that may in turn affect learning and transfer? These processes include the effects of student building performance, resource use, and deep structure noticing on learning and transfer.

Performance and learning. Research suggests that students who focus on deep principles during construction may build better structures (e.g. Worsley & Blikstein, 2014) and learning goals tend to lead to students finding better strategies for task performance (e.g. Gardner, Diesen, Hogg, & Huerta, 2016; Winters & Latham, 1996). Research has also shown that both learning goals (e.g. Miller, Lehman, & Koedinger, 1999) and contrasting cases (e.g. Loibl & Rummel, 2014) improve learning. Therefore, for both performance and learning I hypothesized two main effects and an additive relationship, such that both learning goals and contrasting cases would improve student performance and learning.

Transfer. Here I hypothesized an interaction because literature suggest that learning goals affect how much students attend to resources (e.g. Locke & Bryan, 1969; Rothkopf & Billington, 1979), and contrasting cases have been shown to support student transfer (e.g. Bransford & Schwartz, 1999; Schwartz et al., 2011). I argue that there is no work indicating that contrasting cases support transfer when students are given an outcome goal. Therefore, I hypothesized that students would need learning goals to notice the deep structure in the cases, and the cases would be needed to transfer. For these reasons, I predicted an interaction between task goal and contrasting case use, such that students would need both a learning goal and contrasting cases in order to transfer.

Processes. I hypothesized that learning goals would improve the perceived value of resources, which should improve learning and transfer. As noted above, I predicted that learning goals would be needed to notice the deep structure in the cases, which I predicted would improve transfer.

Study 1 Method

To investigate these research questions, an empirical study explored student learning and performance from an engineering design task where contrasting cases were used and task goals were manipulated**.** All participants were given a building challenge similar to the challenges students receive in many engineering design curricula. Students were instructed to build a freestanding structure that can hang 10.5" off the edge of a table using Legos (for example of student structures, see Figure 1). The activity is meant to engage students in a task that requires application of knowledge of center of mass.

Center of mass is a weighted average that determines the location of an object's point mass, or where all the mass of an object would be if the object were compressed into a single point (Figure 2). It is a weighted average, because it is calculated by finding the average mass of an object, with each mass being "weighted" differently depending on how far it is from some discrete reference point. In this way, parts of an object that are heavier or farther away pull the center of mass closer to them.

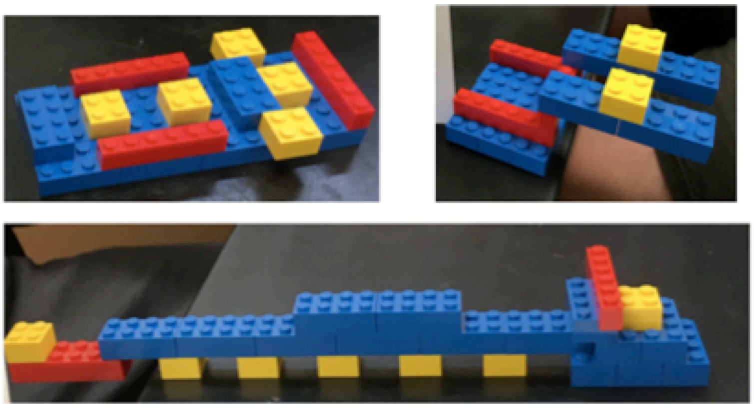


Figure 1. Example student structures from the engineering design task.

For this challenge, each Lego acts as a point, and the distance each Lego is placed from the center of the structure (x_i), along with each Lego's weight (m_i), over the structures total weight ($\sum m_i$) affects the location of the center of mass ($X_{\text{center of mass}}$) within the structure. Furthermore, a structure can balance just by resting on its center of mass. Therefore, to complete the challenge, a participant's structure has to optimize the 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 onto the table as possible. Only then will the structure balance while extending 10.5" off of the table.

$$X_{center\ of\ mass} = \frac{m_1x_1 + m_2x_2 + \ldots + m_nx_n}{m_1 + m_2 + \ldots + m_n} = \frac{\sum m_i x_i}{\sum m_i}$$

Figure 2. Equation for center of mass

Manipulation

There were two main manipulations: a contrasting cases manipulation and a goal manipulation.

For the contrasting case manipulation, half the students were randomly assigned to reflect on contrasting cases (see Figure 3). Students were given front and side images of all the cases, so that they could see that all the bases (in grey) were the same for each case and that the weights (in red or yellow) were the same amount for each case, although weights were placed differently by case. Cases were explicitly designed to highlight the key relationship between mass and distance when calculating center of mass. For example, by comparing and contrasting certain cases (e.g. cases A and C) students could see that the location of the weight mattered, because the two cases have the same weight, but that weight is distributed differently within the structure. Cases also addressed common student misconceptions, such as whether the height or width of the structure matters. For example, by comparing cases E and F students saw that two structures stuck the same amount off the table, even though one was taller and one was wider, because they had the same amount of weight in the same part of the structure.

During two reflections, students looked at these cases and answered a series of questions that asked students to draw specific comparisons between the structures, to elucidate which features caused certain structures to stick out more than others. For example, students were asked to think about the similarities and differences between the structures, and then answer the questions, “what do you notice about the structures that stick out the most?” and “what do you notice about the structures that stick out the least?” Work has shown that this type of bootstrapping helps students to process contrasting cases more effectively (Kurtz, Miao, & Gentner, 2001). The other half of students, who did not receive cases, reflected on working with the task materials, and what it meant to be an engineer. For example, students were asked, “what difficulties might you come across during this challenge?” and “give an example of something you did during the build task that made you feel like an engineer” (for a full list of reflection questions for this reflection, see Appendix B). These questions were inspired by engineering design activities that teach students the engineering design process, or the role of an engineer as a key component of the engineering design curriculum (e.g. Lachapelle & Cunningham, 2007).

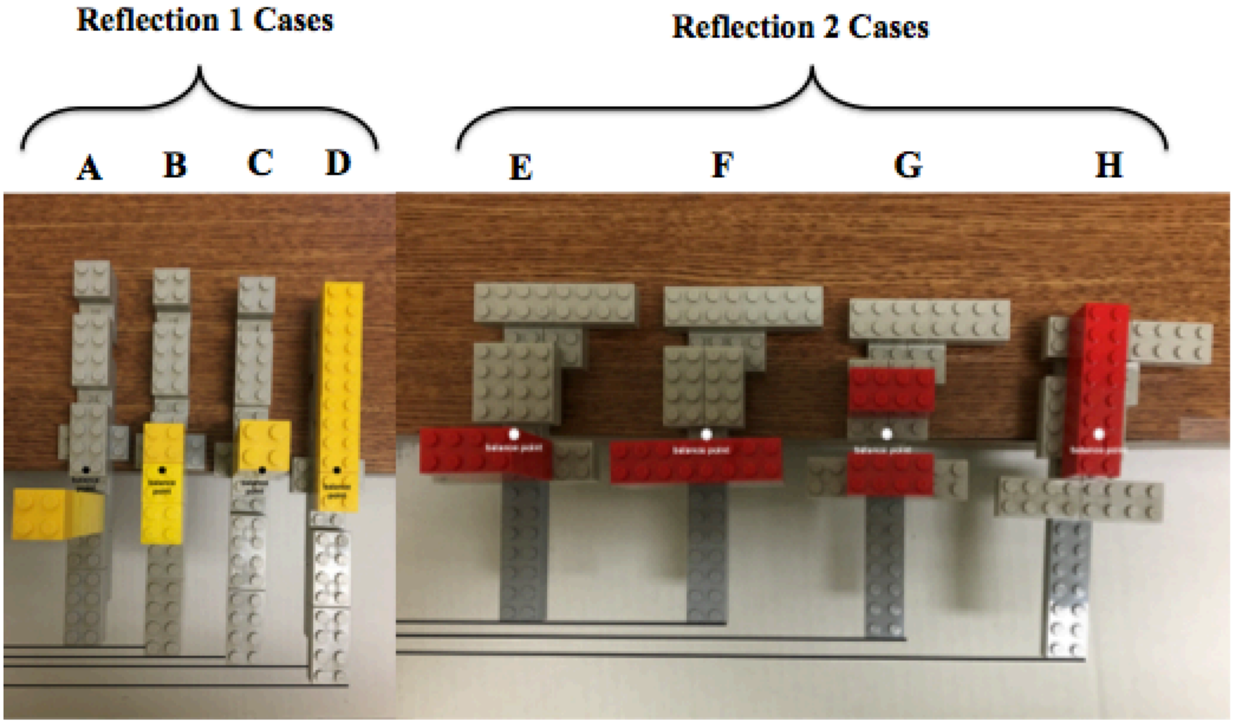


Figure 3. Contrasting cases for both reflections, labeled with their center of mass.

For the goal manipulation half the students were randomly assigned an outcome goal, which was to, “build a structure that can stick 10.5” off of a table”. The other half of the students were given a learning goal, stated as —“Figure out a **rule** that indicates where a structure’s balance point is. Make sure your rule explains why some structures stick out more than others.” Students with the learning goal were told that if they identified the correct rule, it would tell them how to build a structure that could stick 10.5” off the table. Therefore, the engineering design task was framed as a way for students with the learning goal to test the quality of their rule (for full task sheets, see Appendix B).

Participants

A total of 172 students were recruited for participation in the study. Students were 11th graders taking science classes near the end of the school year at a racially diverse urban public high school in New England. The school population was 43% White, 16% Black, 29% Hispanic, 9% Asian and 3% other, with 58% of the student body receiving free or reduced lunch. The school ranked in the 24th percentile of high schools on state test scores. Students from several science classes at the school opted into the study. Students from across these classes were pulled from their typical science class to participate in the study with other students taking science at that time. Within each assigned study period (which from here forward I will simply refer to as "period"), students were randomly assigned to a task goal, and a type of reflection activity. Ultimately this created 4 conditions within each period: learning goal and contrasting cases reflection (n = 19), outcome goal and contrasting cases reflection (n = 23), learning goal and engineering reflection (n = 24), outcome goal and engineering reflection (n = 20). Only students who were present for every day of the study were included in the final analysis. After accounting for this attrition, 86 students were used in the final analysis.

Procedure & Materials

Students participated in the study for one period a day, which ranged from 42 to 68 minutes in length, for five school days (Figure 4).

On the first day, students took a pretest and were given their task goal (either learning or outcome) for the engineering design activity. Over the course of days two and three, students did the engineering design task individually. Students had three "build periods" to work with the Legos on their own as they tried to reach their assigned goal. Before each build period, students had time to plan, and after each build period students evaluated how effective their builds were. Between builds 2 and 3 students received a short lecture about center of mass. This design was meant to emulate a common engineering design task. For example, students were given multiple build periods so that they could iterate upon their designs. They were given strategic points to stop and think about what they were building, look at some examples, and get some direct instruction on the core principle of the problem. These types of interventions between builds are common to engineering design activities, where students are asked to think critically between iterations to improve their designs.

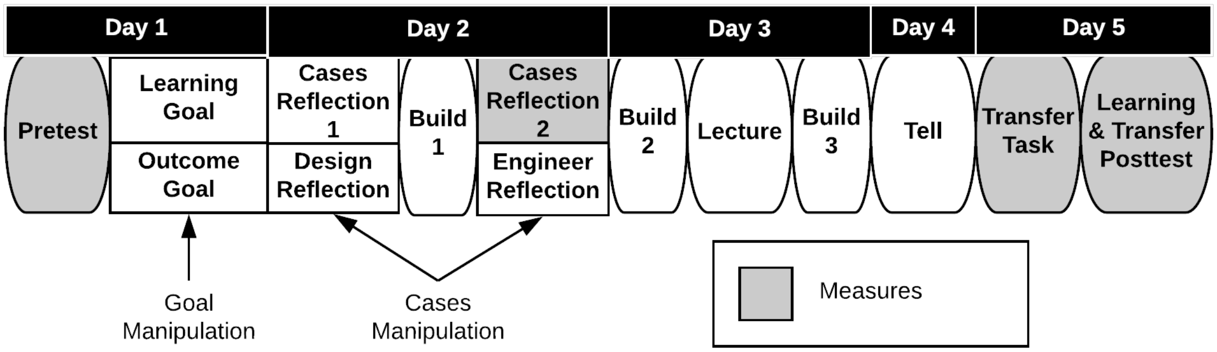


Figure 4. Study 1 procedure.

Before and after build 1, students did a reflection. In the contrasting cases condition, students reflected on a set of Lego cases (Figure 3), meant to highlight deep features of center of mass which were the signifcance of mass, the distance of each mass, as well as the deep structure of the multiplcative relationship between those two variables. The no cases condition did a “design reflection” where they answered questions about how to work with the materials (e.g. “what is difficult about working with Legos?”) and setting expectations for the build (e.g. “what difficulties might you come across during this challenge?”). All students reflected with a partner to promote deep processing. Students then filled out their own individual reflection sheet, which differed by condition (Appendix B). Students did a section reflection, with the same partner, in the middle of the engineering design activity. During this second reflection, contrasting cases condition students looked at another set of cases (Figure 3), and the remaining students did the "engineer reflection" which prompted them to think about on how they were doing with the task (e.g. "what is difficult about this building task?" and "what is easy about this building task?").

In the fourth day, students received a full "Tell" where the principal investigator explained the equation for center of mass. This idea comes from the preparation for future learning (PFL; Bransford & Schwartz, 1999) literature, especially the problem solving before instruction PFL literature (for a review see Loibel, Roll, & Rummel, 2017) where students commonly first struggle with an ill-defined problem before getting formal direct instruction, called the "Tell". The exploratory problem solving stage allows students to uncover knowledge gaps, which can then be filled in by the direct instruction of the Tell. During the Tell students were instructed on the significance of each component of the equation, as well as how the equation could be applied to arrive at the optimal structure for the engineering design task. Furthermore, the Tell addressed several common student misconceptions that students have during the engineering design activity such as the importance of making the structure taller or wider to "add mass". Finally, the tell addressed how to find the center of mass of a two-dimensional object, and why the center of mass needs to be over the base of an object in order for it to balance.

On the fifth and final day, students did a transfer construction task, to evaluate how well their understanding of center of mass could be applied to a different engineering activity. This transfer task is described in the measures section below. Students then took two posttests that contained both learning and transfer questions.

Measures

Task Performance. Task success was measured by experimenter records of how far off the table each student's structure could hang by the end of each build period. Measurements were made in inches, and rounded to the nearest ¼ inch.

Tests. Students took three pencil-and-paper tests over the course of the study, measuring prior knowledge, learning, and transfer. The pretest and posttest questions were either equivalent, or isomorphic (Figure 5). A second posttest was given immediate after the first. It provided students with the equation for center of mass, and then tested a more difficult array of transfer problems.

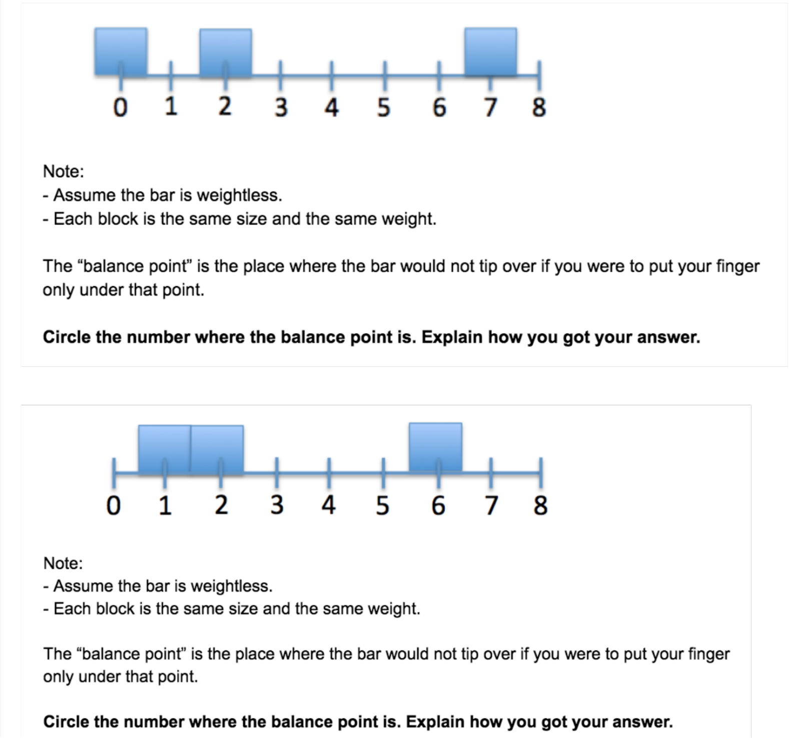
For all tests, a coding manual was made to evaluate how well students understood center of mass. Two different researchers then blind coded 20% of the data. For each question, an inter-rater reliability of $\kappa > .70$ was achieved, and one master coder went through to code the rest of the data. Four transfer test questions were multiple-choice questions, and therefore followed a no-inference coding scheme. Kappa values for all other test questions are listed below (Table 1).

Table 1

Kappa Values for Various Learning and Transfer Test Questions

	Learning		Transfer	
Question	Pre	Post	Pre	Post
Center of Mass Definition	0.74			
Center of Mass Features	0.87			
Balancing on a Fulcrum			0.81	0.82
Explain a Sculpture			0.70	0.90
Number Line			0.96	
Balancing a Person				0.74
Balance in a Three Object System				0.78
Center of Mass Height and Stability				1.00
Explain the Transfer Task				0.77

Prior Knowledge. Prior knowledge was measured by averaging student performance across a six-item pencil-and-paper pretest. This test evaluated student's declarative knowledge about center of mass (learning) using two questions, and their ability to apply that knowledge to a series of problems in other contexts (transfer) using four questions. The two questions on the learning pretest were “What is center of mass? Give a definition” and “Explain what features of a structure affect the location of its center of mass. Describe precisely HOW these features impact the center of mass”. The transfer pretest asked students to apply center of mass principles to problems set in different contexts ($\alpha = .40$). Reliability for this measure was fairly low because students did not know anything going into the pretest, so they tend to answer questions randomly, leading to low inter-item correlations. Also, there were floor effects on this measure, which contributed to the low reliability.



Note:
- Assume the bar is weightless.
- Each block is the same size and the same weight.

The “balance point” is the place where the bar would not tip over if you were to put your finger only under that point.

Circle the number where the balance point is. Explain how you got your answer.

Note:
- Assume the bar is weightless.
- Each block is the same size and the same weight.

The “balance point” is the place where the bar would not tip over if you were to put your finger only under that point.

Circle the number where the balance point is. Explain how you got your answer.

Figure 5. Example transfer question that was isomorphic between the pretest (top) and the posttest (bottom).

Learning. The learning posttest questions were identical to the two learning pretest questions.

Transfer. The transfer posttest was comprised of 11 questions ($\alpha = .67$). These questions asked students to apply conceptual knowledge about center of mass to new problems in a variety of contexts that differed in the functional context and modality (Barnett & Ceci, 2002) from the engineering design activity (Figure 5). A portion of these questions were preparation for future learning questions where students were taught a new concept about center of mass and provided a worked problem. They then had to apply that knowledge to a new problem.

Transfer Task. The transfer construction task asked students to make a paper bird balance on a straw by adding paper clips to it. To be successful on this task, students had to move the center of mass on the bird to the left and down. This was considered a transfer task because students had to use the basic principle of center of mass, but in a new task and using different materials. Furthermore, to be successful, students had to think about center of mass in a new dimension (up down, along the y-axis) from the learning task (which was only concerned with center of mass along the x-axis). To measure student success, birds were divided into 4 quadrants and experimenters counted how many paper clips students put in each quadrant (Figure 6). Transfer was measured by how many paper clips students put on the bottom half of their bird. Putting weight on the left half of the bird was not considered transfer, because it involved the same horizontal weight placement principles students learned in the engineering design task. In contrast, placing weight low measured how well students took new information presented in the tell and applied it to a novel context.

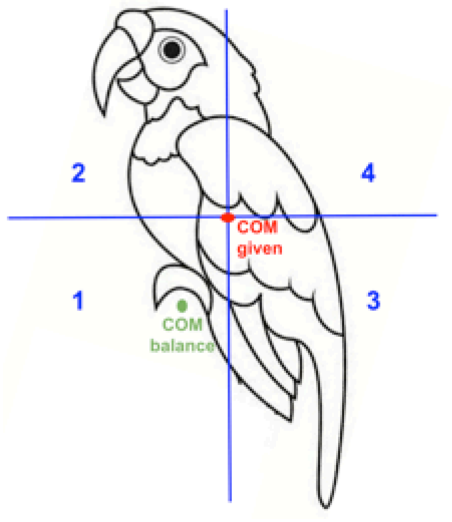


Figure 6. Bird given to students during the transfer construction task. The dot labeled "COM given" indicates where the center of mass of the bird was when the bird was given to students without any paper clips on it. The dot labeled "COM balance" indicates where the center of mass needed to be moved to in order for the bird to balance on a straw. Students were told to make the bird balance on a straw by adding paper clips to it. Adding paper clips to quadrants 1 and 3 moves the center of mass down. This weight placement was considered a measure of transfer.

Deep Structure. Whether or not students noticed the deep structure was only measured for students who were given contrasting cases to reflect on. When looking at the cases students answered a series of questions, such as "what do you notice about the structures that stick out the most?" Only responses from the second reflection are used, in an attempt to capture whether or not students noticed the deep structure by the end of both cases reflections. Reflections were dichotomously coded for whether students noticed the deep structure or not. Two different researchers blind coded the same 20% of the data independently. An inter-rater reliability of κ = .79 was achieved. Coders then split up to code the remaining data.

Study 1 Results

Analysis model decisions were based on the type of measure being evaluated. Most measures were evaluated using an ANOVA model. Count data was originally analyzed with a

Poisson regression. However an ANOVA is reported because results from both models showed the same effects and the ANOVA was more interpretable.

Exploratory analyses indicated that there were period effects for posttest scores, but period effects didn't exist for other outcomes. A period variable was therefore added as a random factor to both learning and transfer models that evaluated posttest performance. There was no effect of gender on any outcome, so that was not added as a variable to any analyses.

Given that the contrasting case reflections were done in dyads, there is a chance that other outcome measures were not truly independent, because students learned together. This issue has been addressed in past work where students learn in dyads but are measured individually (Mercier, 2016). To test for independence between measures within dyads, intra-class correlation was calculated for dyads on all outcome measures (Table 2). The cutoff for significance was a two-tailed p-value of < .20 (Kenny, Kashy, Cook, & Simpson, 2006). The only outcome measures with significant ICC were learning and transfer posttest scores.

Table 2

ICC Between Dyads on Various Outcome Measures

Measure	*r*	*F*	*df*	Sig.
Final Build Length	0.09	1.21	48,49	.25
Learning Posttest	0.30	1.85	48,49	.02†
Transfer Posttest	0.49	2.94	48,49	< .01†
Transfer Task	0.01	1.01	48,49	.49
Deep Structure	0.28	1.78	24,25	.32

Note. $^{\dagger}p < .20$

To address pair effects for posttest measures, a generalized linear mixed-effect model was run with pair as a random effect. This model is a hierarchical linear model where level one models the effects of fixed effects like task goal, contrasting case use, pretest scores, and period on individual students' posttest scores. Level two models the effects of student pairs, on the intercept for the level 1 model.

$$\text{Level 1: } Y_{ij} = \beta_{0\mathrm{j}} + \beta_1 GOAL_{ij} + \beta_2 CASES_{ij} + \beta_3 PRETEST_{ij} + \beta_3 PERIOD_{ij} + e_{ij}$$

$$\text{Level 2: } \beta_{0\mathrm{j}} = \gamma_{00} + u_{0j}$$

Task Performance

To look at condition effects on task performance, a two-way repeated measures ANOVA with goal (learning vs. outcome) and type of reflection (cases vs. no cases) as between-subjects factors, and time as a within-subjects factor indicated an interaction between goal and reflection type on task performance $F(1,82) = 7.40$, $p = .01$, $\eta_p^2 = .08$. Planned comparisons were conducted using Bonferroni adjusted alpha levels of .025 per test. There were no significant effects of reflection type between goal conditions with this correction. Descriptively however, students who were given an outcome goal and cases built structures that stuck almost an inch farther off the table than students who did not have cases (Table 3). There was also a significant interaction of case condition over time, $F(2,81) = 3.71$, $p = .03$, $\eta_p^2 = .08$. Planned comparisons were conducted to see the effect of cases on performance during each build period, using Bonferroni adjusted alpha levels of .0167 per test. However, there were no significant differences between cases conditions on build periods at this level. Finally, there was a main effect for time, $F(2,81) = 62.95$, $p < .001$, $\eta_p^2 = .61$, and this pattern was linear, $F(1,82) = 126.71$, $p = .03$, $\eta_p^2 = .61$, such that all student structures improved over time. There were no other main effects or interactions *p's* > .26.

Table 3

Means (with SD) of Student's Structure Length (in Inches) Over Time

Goal	Reflection Condition	Build 1	Build 2	Build 3
Learning	Cases	5.05 (1.87)	6.32 (2.58)	7.39 (2.17)
	No Cases	4.98 (2.33)	7.47 (2.34)	8.57 (1.30)
Outcome	Cases	6.62 (1.86)	7.68 (1.76)	8.37 (2.01)
	No Cases	4.84 (1.82)	6.85 (1.54)	7.74 (1.87)

Posttest Outcomes

Learning. Students' goal did not affect learning, when controlling for period effects and prior knowledge. To evaluate learning performance at post, a hierarchical linear model was run with learning pretest score, period, task goal, cases, and a task goal by cases interaction as fixed effects at level one. Pair was modeled as a random effect at level two. There were no significant main effects or interactions, p's > .10 (Table 4).

Transfer. Students' condition also did not affect transfer, when controlling for period effects and prior knowledge. To evaluate transfer test performance at post, a hierarchical linear model was run with transfer pretest score, period, task goal, cases, and a task goal by cases interaction as fixed effects at level one. Pair was modeled as a random effect at level two. There was a main effect for pretest, $t(72.48) = 3.75$, $p < .01$, but there were no other effects, p*'s* > .34. So while task goal and type of reflection did not seem to affect transfer posttest scores, there was a significant effect of prior knowledge (Table 4).

Transfer Task

Performance on the transfer construction task indicated that students who were given both contrasting cases and a learning goal transferred more. A two-way ANOVA with goal and cases condition as between-subjects factors showed a significant interaction between students' task goal and whether or not they received cases when measuring weight placement during the transfer task $F(1,82) = 6.72$, $p = .01$, $\eta_p^2 = .08$ (Table 4). Planned comparisons with a Bonferroni alpha correction set at .025 confirmed that if students were assigned a learning goal, then they put more weight low on the bird if they were given cases $F(1,82) = 8.06$, $p = .01$, $\eta_p^2 = .07$. Similarly, of students who were given cases, then they put the weight lower on the bird if they also had a learning goal $F(1,82) = 6.18$, $p = .02$, , $\eta_p^2 = .09$. There were no main effects for either condition, *p*'s > .16.

Table 4

Means (with SD) of Learning and Transfer Outcomes by Condition

Goal	Reflection Condition	Learning Posttest Score	Transfer Posttest Score	Transfer Task Score [# of paperclips]
Learning	Cases	0.38 (0.20)	0.43 (0.16)	4.11 (2.60)
	No Cases	0.47 (0.22)	0.50 (0.20)	2.17 (2.32)
Outcome	Cases	0.46 (0.30)	0.44 (0.20)	2.39 (1.80)
	No Cases	0.47 (0.25)	0.44 (0.17)	2.95 (2.16)

Noticing the Deep Structure

The noticing measure came from coding students' responses to the second contrasting cases reflection, so the following analysis is only performed on goal conditions within the contrasting cases condition.

Within contrasting case reflection groups, students' assigned learning goal did not seem to affect whether or not students noticed the deep structure of the problem. Across both goal conditions, students typically failed to notice the deep structure (Table 5). A Chi-Square test showed that deep structure noticing did not significantly differ across the two task goal conditions, $X^2(1, N = 42) = 0.02$, $p = .89$ two-tailed.

Table 5

Number of Students Who Noticed the Deep Structure by Goal Condition

	Noticed Deep Structure?	
Goal	No	Yes
Outcome	20	4
Learning	19	5

Mechanisms of Learning and Transfer

All models shown below looking at the effect of task performance and deep structure noticing on learning and transfer for only for the students who were given contrasting cases (n = 48). These models were first run with both goal and contrasting case use included. However, there were no main effects or interactions for either condition, so these variables were removed for the following analyses. For each learning and transfer outcome, a hierarchical linear model was run with fixed effects for building performance, noticing the deep structure, period, and pretest scores at level one, and a random effect for student pairs at level two. Deep structure noticing did not predict transfer performance, so I did not include an interaction effect between those two factors in the model. Models are presented in Table 6 below.

Table 6

Hierarchical Linear Models of Learning and Transfer Outcomes

	Fixed Effects					Variance Components	
	Coef	*SE*	*t*	Sig.		Estimate	*SD*
Model 1: Learning Posttest					σ^2	0.04	0.20
Intercept	0.20	0.15	1.32	.20	τ_{00}	0.02	0.13
Build 3 Length	0.02	0.02	1.41	.17			
Deep Structure Noticing	0.22	0.09	2.49	.02*			
Pretest	0.51	0.32	1.61	.12			

Model 2: Transfer Posttest					σ^2	0.01	0.10
Intercept	0.28	0.07	3.95	< .01**	τ_{oo}	0.01	0.09
Build 3 Length	0.02	0.01	2.33	.03*			
Deep Structure Noticing	0.09	0.04	2.00	.05[§]			
Pretest	0.16	0.11	1.51	.14			
Model 3: Transfer Task					σ^2	5.46e+00	2.34e+00
Intercept	3.29	1.39	2.37	.02*	τ_{oo}	6.81e-14	2.61e-07
Build 3 Length	-0.04	0.17	-0.26	.80			
Deep Structure Noticing	1.37	0.97	1.41	.17			

Note. Period is controlled for in each model at Level 1 as a fixed effect. Pair effects are controlled for at level 2 as a random effect on the intercept. The effects of build length on all outcomes are the same significance level if done on the full dataset (p = .18 for learning, p = .01 for transfer posttest, p = .09 for transfer task).
[§]p < .01, *p < .05, **p < .01

There was a significant main effect of deep structure noticing on learning, and there was a trend towards deep structure noticing predicting transfer posttest scores (Table 7). Regardless of condition, students who noticed the deep structure during the cases comparison did better on the both posttests, controlling for prior knowledge. Additionally, students who built longer structures did better on the transfer posttest, controlling for prior knowledge.

Table 7

Mean Learning and Transfer Outcomes (with SD) by Deep Structure Noticing Level

Deep Structure	Learning Posttest	Transfer Posttest	Transfer Task
No	0.36 (0.25)	0.40 (0.19)	2.94 (2.37)
Yes	0.71 (0.27)	0.59 (0.21)	4.29 (3.06)

Study 1 Discussion

Results showed that learning goals and contrasting cases improved transfer task performance and deep structure noticing improved learning.

First, I confirmed the hypothesis that both a learning goal and contrasting cases were needed for students to transfer knowledge to a different engineering design task. Students who had both a learning goal and cases did better on the transfer task, but there were no main effects for either condition individually, suggesting that both a learning goal and contrasting cases are needed to transfer. However, it is unclear exactly how these manipulations affected transfer, given that goals and contrasting cases did not affect learning, transfer posttest performance, or deep structure noticing during the contrasting cases reflection. It may be that students who were given a learning goal and contrasting cases were able to build some intuitive knowledge of center of mass that helped them perform on a construction task did not affect their formal understanding of center of mass. This could have also been a preparation for future learning effect, where the learning goal and contrasting cases together helped students more effectively learn from the Tell, which taught students that when balancing an object, the center of mass has to be kept low. It may have been that students who had a learning goal and contrasting cases felt that they would get more out of the Tell, and therefore paid more attention to it. In contrast, students with an outcome goal probably weren't that interested in the principles mentioned in the Tell because they were done with the task and these principles were no longer relevant to achieving their goal.

While deep structure noticing did not predict transfer task performance, it was associated with higher learning and transfer posttest scores. This may explain why task goals and contrasting cases failed to affect learning and transfer, because they failed to significantly affect deep structure noticing. However, the relationship between deep structure noticing, and transfer was only marginal, so these findings should be taken with caution. Furthermore, deep structure noticing was only measured for the students given a contrasting cases reflection. Therefore, it is hard to tell if task goals had an effect on deep structure noticing during the task, outside of the contrasting cases reflection.

Limitations

This study suffered from several limitations. First, the sample size for each condition was relatively small, centering around 20 students. This small sample size may have limited the power available to detect learning or transfer differences between conditions. Before conducting the study, a power analysis indicated that 210 students were needed to see an effect of condition on learning and posttest scores, assuming a medium effect size. However, only 170 students could be recruited at the given school site, and only 93 of those students opted to participate in the study. Another seven students were lost to attrition, making the sample potentially too small to detect these effects. (Note that the learning and transfer pretest scores of students who dropped out of the study did not significantly differ from pretest scores of students who stayed and made up the study sample, p's > .32).

Furthermore, the pre and posttests were not counterbalanced, which could have made it difficult to measure how much students learned, or transferred from the study, especially if the tests were not of equal difficulty. The transfer posttest may have also been too hard for students. Easier questions may have better detected what students could reasonably learn from such a brief intervention. This dosage problem may have been compounded by the fact that students did not have much time on the engineering design task, and constantly switching between different activities within a period. This might have hurt students' ability to orient themselves and then settle into deep thinking within any given activity.

Field observations also indicated that although students understood their unique, assigned task goal at the beginning of the task, during building students from both goal conditions took on an outcome goal. This could have been because it was easier for students to produce their own feedback for the outcome goal than the learning goal. Students could measure their structure at any time, but didn't seem to know how to tell if their rule was good or not. So, the task goal manipulation did not seem to be as strong as was originally intended.

As a final side note, there were some log data collected on students during the task, but it was corrupted, and thus is not reported here. The log data was intended to capture student resource use during the task, such as if students were viewing the lecture or contrasting cases during build periods. Researcher observations indicated that students with a learning goal may have found more value in the learning resources, but that could not be confirmed with data. A second study therefore attempted to address these issues and replicate some of the findings from study 1.

Study 2 Method

Study 2 took a deeper dive into how learning versus outcome task goals affect students' performance, learning, and transfer processes. Study 1 indicated that the presence of a learning goal and contrasting cases helped students transfer knowledge to another construction task. However, limitations of study 1 made it difficult to ascertain how students were able to transfer under these conditions. In study 2, all students were given a contrasting cases reflection, and only task goals were manipulated. This increased the sample size of each condition, which made it easier to detect how task goals may affect transfer when contrasting cases are present.

Study 2 also attempted to improve some of the processes and measures of study 1. The goal manipulation was strengthened, the test measures were enhanced, a measure of how much students valued the learning resources was added, and the study procedure was simplified.

Procedure

In study 2 students were randomly assigned to one of two conditions: learning goal or outcome goal. All students reflected on contrasting cases. Additionally, students had physical copies of the cases in their classroom, which they could look at in real life, in addition to the front and side images of the cases provided as colored printouts for each pair. Students were given the same goals, engineering design activity, and contrasting cases reflection from study 1. To address study 1 limitations, enhancements were made to the study design (Figure 7).

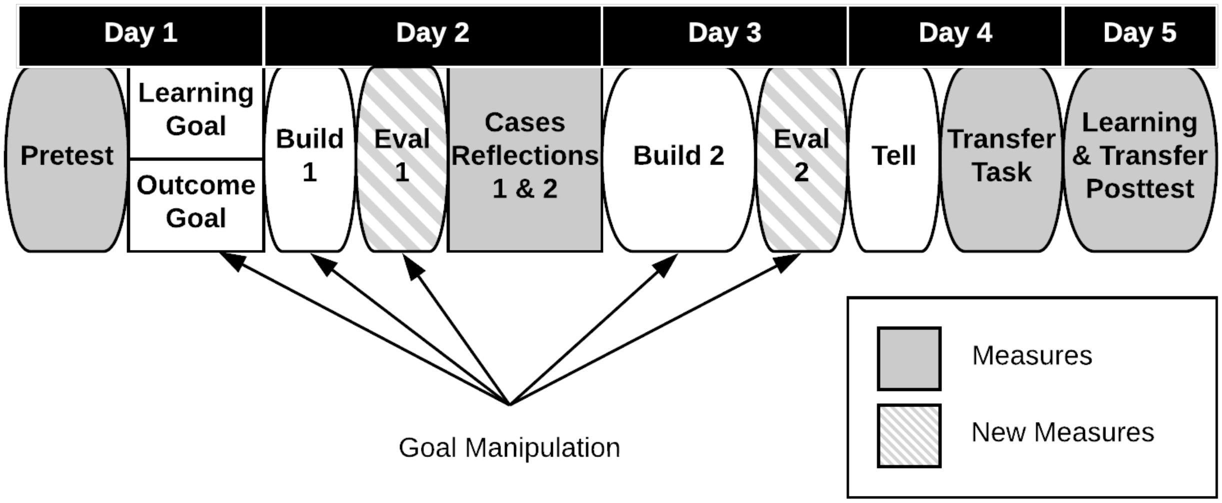


Figure 7. Study 2 procedure. Notes sheets during each build period prompted students to think about their goal. Evaluations after each build also reinforced the goal manipulation.

To strengthen the goal manipulation, students were given notes sheets to fill out during each build (see Appendix B). These sheets prompted students to keep track of how close they were to reaching their goal as they worked with the Legos. All students were prompted fill out these notes sheets throughout each build period, so students were constantly reminded of what their goal was, and how to measure it. This was intended to reinforce the goal manipulation during the build (Figure 7). Students were also assigned to work in dyads while building. The intention was that students would hold their partner accountable to work towards their assigned task goal. Video data and field notes suggests that students did remind their partner of their goal throughout the activity.

Next, several activities were combined into larger blocks to prevent the constant switching between activities. Build periods 2 and 3 were combined. Similarly, reflections 1 and 2 were turned into a single reflection period, where students saw each set of cases back-to-back. Planning periods before each build were removed, and builds were made slightly longer. Finally, instead of giving students a lecture on center of mass, students were given the script for the center of mass lecture as a reading, which they could reference at any time during build 2, along with color photographs of all the cases.

A building evaluation was added after both builds, as a pencil-and-paper based survey. This survey included a questionnaire about how valuable the resources were in helping students reach their task goal during each build period.

Participants

For study 2, a new set of 108 students was recruited. Students were 10th, 11th, and 12th graders in the accelerated science track, at a suburban public high school in the Mid-Atlantic United States. The school population was 11% White, 2% Black, 84% Hispanic, and 3% Asian, with 72% of the student body receiving free or reduced lunch. It ranks in the 25th percentile in state test scores. Students participated in the study during their usual science class. Some science classes were run during the same period, so like study 1, period was used as a variable to control for when students participated in the study. Students were randomly assigned a task goal within each period. Only students who were present for every day of the study were included in the final analysis. After this attrition, 78 students remained (Learning Goal n = 39, Outcome Goal n = 39).

Measures

Changes made to measures for study 2 are listed below. Build performance, transfer task and deep structure noticing measures were identical to study 1.

Tests. Students took three pencil-and-paper tests. The pretest and first posttest were lengthened to 8 items and counter-balanced. This 8-item test included 4 learning and 4 transfer items. For all new problems, a new coding manual was made. Two researchers blind coded 20% of the data and achieved, an inter-rater reliability of $\kappa > .70$ (Table 8). Items where inter-rater reliability could not be achieved had all data was coded by two raters who discussed all disagreements. For items that required inference coding and inter-rater reliability was achieved, one master coder coded all the data.

Table 8

Kappa Values for Various Learning and Transfer Test Questions

	Learning	Transfer	
Question	Pre & Post	Pre & Post	Post Only
Center of Mass Features	0.76		
Equation Explanation	0.89		
Center of Mass Over a Base		0.78	
Balancing on a Fulcrum		0.75	
Explain a Sculpture		0.71	
Number Line		0.96	
Torque Preparation for Future Learning Question			0.73
Center of Mass Height and Stability			1.00
Explain the Transfer Task			0.77

Prior Knowledge. Prior knowledge was measured by averaging student performance across the eight-items of the pencil-and-paper pretest. There were four learning and four transfer questions. Student performance was broken up along these two sub-categories to make two pretests: a learning pretest ($\alpha = .20$) and a transfer pretest ($\alpha = .48$). Like study 1, reliability was low in part because students came in with almost no prior knowledge, and therefore answered randomly, leading to low inter-item correlations. Also, there were floor effects on this measure, which contributed to the low reliability. Like study 1, the majority of students got all questions on the learning pretest completely wrong, resulting in an average learning pretest score of almost zero (M = 0.02, SD = 0.06).

Learning. Learning posttest items were added from study 1 to improve scale reliability. Learning was measured by averaging across the four learning items on the pencil-and-paper posttest. These four questions, which were identical across both forms of the test, evaluated students' rote, declarative knowledge about center of mass (α = .72).

Transfer. Several transfer items from study 1 were replaced to improve construct validity. Transfer was then measured by averaging across the 10 transfer questions on the two posttests. However, one question from the second posttest was cut because students couldn't read the question, due to poor photocopying. Furthermore, when reliability was computed for the transfer scale, this problem negatively correlated with students final transfer scores.

Transfer was therefore measured by computing an average across the remaining nine questions. Reliability between these nine questions was low (α = .44), but they were not intended to measure a single skill. Instead, they were purposefully designed to evaluate students' ability to transfer across many different contexts and problem types. Additionally, students in this high school population were much more homogeneous than the students in study 1, which reduced the scale variance, which in turn reduced alpha. The scale variance across transfer problems in study 2 (2.06) was half what it was in study 1 (4.05). This might have been because all students in study 2 took accelerated science, while in the first study students came from a wider selection of science classes.

Value of Resources. To measure how much students valued the resources given to them, students were given a pencil-and-paper survey at the end of the second build. This survey listed resources that students could have used during the build including their imagination, their partner, their notes, prototypical structures from real life, the center of mass reading, and the contrasting case structures. Students were asked to indicate how important each resource was in helping them achieve their task goal on a scale of 1 (Not at all important) to 5 (Very important), with 3 indicating neutrality. Student scores were averaged into a single score.

Study 2 Results

Models used for study 2 were identical to the models used for the same hypotheses in study 1. For new analyses, the statistical model was chosen based on the nature of the test variables. Preliminary analysis indicated no effects of grade, gender, or period on any outcome variable, so there are no variables accounting these effects in any model.

Like study 1, ICC for each outcome variable was calculated (Table 9). The outcome measures with a significant intra-class ICC values were transfer task scores, noticing the deep structure, and students' perceived value of the resources. As in study 1, pair was added as a random effect in the model for each outcome that had a significant ICC value.

Table 9

ICC Between Dyads on Various Outcome Measures

Measure	*r*	*F*	*df*	Sig.
Final Build Length	-[a]	-	-	-
Learning Posttest	0.10	1.21	43,44	.27
Transfer Posttest	0.00	1.00	43,44	.50
Transfer Task	0.34	2.05	43,44	.01[†]
Deep Structure	0.60	3.98	43,44	< .01[†]
Resource Valuing	0.27	1.73	43,44	.04[†]

Note. [†]p < .20

[a] All students built in dyads so there was no need to calculate ICC for this variable.

Task Performance

As in study 1, there was no main effect of task goal on performance. A one-way repeated measures ANOVA with goal as a between-subjects factor indicated a main effect for time $F(1,42) = 45.85, p < .001, \eta_p^2 = .52$, since all student dyad's structures improved over time (Table 10). However there were no other significant main effects or interactions p's > .15.

Table 10

Means (with SD) of Average Dyad Structure Length (in inches) By Condition

Goal	Build 1	Build 2
Learning	4.69 (2.30)	7.01 (2.27)
Outcome	5.38 (2.48)	7.38 (1.38)

Posttest Outcomes

Learning. As in study 1, students' goal did not affect learning, when controlling for prior knowledge. To evaluate learning performance at post, an ANCOVA with task goal as a between-subjects factor, and learning pretest score as covariate was run. There was no significant effect of task goal on learning posttest scores, $p = .31$(Table 11). There was a significant main effect for pretest score, $F(1,75) = 1.66, p = .02, \eta_p^2 = .02$.

Transfer. However, learning goals did improve transfer posttest scores. This is contrary to study 1, where goals did not affect transfer. To evaluate transfer performance at post, an ANCOVA with task goal as a between-subjects factor, and transfer pretest score as covariate was run. There was a significant effect of task goal on transfer posttest scores $F(1,75) = 5.17, p = .03, \eta_p^2 = .07$. Students with a learning goal, performed better on the transfer posttest than students with an outcome goal, controlling for prior knowledge (Table 11). There was a significant main effect for pretest score, $F(1,75) = 11.50, p < .01, \eta_p^2 = .13$.

Transfer Task

As in study 1, descriptively students with a learning goal did better on the transfer task. To evaluate transfer task performance, a linear mixed-effects model was run with task goal as a fixed effect and pair as a random effect. There was a trend towards learning goals affecting weight placement on the bird, *t*(33.1) = 1.98, *p* = .06. Specifically, students who were given a learning goal put more paper clips in the lower half of their bird (Table 11).

Table 11

Means (with SD) of Learning and Transfer Outcomes by Condition

Goal	Learning Posttest Score	Transfer Posttest Score	Transfer Task Score [# of paperclips]
Outcome	0.37 (0.29)	0.44 (0.16)	2.77 (2.38)
Learning	0.43 (0.29)	0.50 (0.15)	4.28 (4.06)

Noticing the Deep Structure

Similarly to study 1, students with a learning goal did not notice the deep structure by the end of the contrasting cases reflection more effectively than students with an outcome goal. Across both goal conditions, students typically failed to notice the deep structure (Table 12). A mixed effects logistic regression was run with deep structure noticing as the outcome, task goal as a fixed-effects predictor, and pair as a random intercept. There was no significant effect of learning goal on deep structure noticing *p* = .15.

Table 12

Number of Students Who Noticed the Deep Structure by Goal Condition

	Noticed the Deep Structure?	
Goal	No	Yes
Outcome	35	4
Learning	28	11

Resource Valuing

Students assigned a learning goal seemed to value the learning resources they were given more during build 2. A hierarchical linear model was run with task goal as a fixed effect and pair as a random effect. There was a significant effect of learning goals on the perceived value of resources, $t(40.88) = 1.98$, $p = .05$. Students with a learning goal valued the resources more (M = 3.65, SD = 0.66) than students who were given an outcome goal (M = 3.32, SD = 0.71).

Mechanisms of Learning and Transfer

As in study 1, the effect of task performance, deep structure noticing, and resource value on learning and transfer were first calculated with goal condition in the model. However, there was neither a main effect of goal nor any significant interactions with goal on any of these relationships. So goal effects were not accounted for in the final models. For each learning and transfer outcome, a hierarchical linear model was run with fixed effects for building performance, noticing the deep structure, resource valuing, and pretest scores at level one. Level two modeled a random effect for student pairs on the intercept of the level one model. Deep structure noticing did not predict transfer performance, so the interaction effect between those two factors is not in the model. Models are presented in Table 13.

Table 13

Hierarchical Linear Models of Learning and Transfer Outcomes

	Fixed Effects					Variance Components	
	Coef	*SE*	*t*	Sig.		Estimate	*SD*
Model 1: Learning Posttest					σ^2	0.07	0.26
Intercept	-0.001	0.27	-0.003	.99	τ_{oo}	0.01	0.12
Build 2 Length	0.003	0.02	0.17	.86			
Deep Structure	0.02	0.09	0.2	.84			

Resource Value	0.10	0.05	2.04	.05*			
Pretest	0.51	0.51	1.00	.32			
Model 2: Transfer Posttest					σ^2	2.04e-02	1.43e-01
Intercept	0.30	0.13	2.29	.02*	τ_{oo}	2.87e-24	1.69e-12
Build 2 Length	0.01	0.01	0.94	.35			
Deep Structure	0.13	0.04	3.15	< .01**			
Resource Value	-0.003	0.03	-0.14	.89			
Pretest	0.28	0.10	2.92	< .01**			
Model 3: Transfer Task					σ^2	9.07	3.01
Intercept	4.66	3.17	1.47	.15	τ_{oo}	2.49	1.58
Build 2 Length	-0.28	0.25	-1.15	.26			
Deep Structure	0.67	1.04	0.64	.52			
Resource Value	0.24	0.24	0.39	.70			

Note. Pair effects are controlled for at level 2 as a random effect on the intercept.
§p < .01, *p < .05, **p < .01

Whereas in study 1 it was only a trend, in study 2 found a significant effect of deep structure noticing on transfer. Students who noticed the deep structure during the cases comparison did better on the transfer posttest, controlling for prior knowledge (Table 14). Additionally, there was a significant main effect of resource valuing on learning posttest scores. Students who perceived the resources as more helpful did better on the learning posttest, controlling for prior knowledge. Nothing was predictive of transfer task performance.

Table 14

Mean Learning and Transfer Outcomes (with SD) by Deep Structure Noticing Level

Deep Structure	Learning Posttest	Transfer Posttest	Transfer Task
No	0.39 (0.29)	0.45 (0.15)	3.27 (3.35)
Yes	0.44 (0.30)	0.57 (0.13)	4.60 (3.46)

Study 2 Discussion

This study replicated the study 1 finding that learning goals improve transfer task performance. Although only a trend, descriptively students with a learning goal consistently more strategically placed weight to improve the bird's ability to balance on a straw. This study also showed that learning goals improved performance on the transfer test, when controlling for prior knowledge. Together, these results suggest that when all students are given contrasting cases, learning goals affect transfer.

Additionally, both studies showed a link between deep structure noticing and transfer. Students in study 2 who were able to notice the deep structure from the cases performed better on problems that required them to apply those concepts in new contexts. This is concurrent with the literature that deep structure noticing is important for transfer. It is strange however that even though transfer performance was greater for students with a learning goal, and deep structure noticing predicted transfer test performance, learning goals did not affect deep structure noticing. This suggests that there may be some other mechanism by which learning goals are affecting transfer. It could be that learning goals were affecting how much students attended to or learned from the Tell, which in turn may have affected how much students were able to transfer.

In addition to these replicated findings, a couple of new relationships were found. Learning goals affected how useful students perceived the learning resources to be. Furthermore, students who perceived the learning resources to be more useful performed better on the learning posttest, controlling for prior knowledge. However, students with a learning goal did not learn more than students with an outcome goal. This inconsistent mediation (MacKinnon, Fairchild, & Fritz, 2007) could have been for several reasons. One reason for inconsistent mediation is if learning goals somehow hurt learning, which would have negated the positive effect of resource value on learning. However, given that learning goals improved learning descriptively, if not statistically, this explanation is unlikely.

General Discussion

This work aimed to understand how various factors, including goals, contrasting cases, and perceived value of resources, affected learning and transfer from an engineering design task.

The most significant relationships were between learning goals and transfer. In study 1, learning goals and contrasting cases improved transfer task performance. In study 2, this finding was replicated as a trend, and there was an effect of learning goals on transfer posttest scores. These results suggest that in general, learning goals aid transfer. This finding is interesting because although goals consistently improved students' ability to transfer, there were no effects of goals on learning or task performance. This suggests that learning goals have some unique effect on transfer specifically.

These studies also looked at the mechanisms of learning and transfer. Results indicated that learning goals improve the perceived value of resources, which in turn improve learning. Deep structure noticing also consistently predicted transfer posttest performance. Given the broad spectrum of literatures covered by this work, there are both theoretical and practical implications for these findings.

Theoretical Implications. For the transfer literature, this work provides empirical evidence supporting how learning goals might affect transfer. Transfer is notoriously difficult to obtain even during the simplest of tasks (Detterman, 1993). This study indicates that learning goals are one way to support student transfer.

Furthermore, this study provides empirical evidence to propose that learning goals may moderate the effect of contrasting cases on transfer. Many learning activities that use contrasting cases to aid transfer include a goal that focuses students on the deep structure of the task (Kapur, 2008; Loibl, Roll, & Rummel, 2017; Nokes & Belenky, 2011; Schwartz et al. 2011). However, I am not aware of any scholarly work that has isolated learning task goals as a critical component of this transfer process. Learning goals however may be necessary for contrasting cases to actually work. The identified interaction between learning goals and contrasting cases is novel because although past work has suggested the role of contrasting cases and learning goals on transfer separately, work has not looked at how these two factors interact to affect transfer.

This work is also novel because of the context that it is situated in. Contrasting case activities are usually heavily scaffolded problems, where students have little choice. Few studies have looked at how contrasting cases might work in a highly noisy environment where students have many choices. There has been some work by Gentner and colleagues (2016) looking at contrasting case use during a building design challenge in a museum setting. However their population was much younger, and they did not explore how student goals affect cases use, performance, or learning.

Finally, this work contributes to the transfer and noticing literature. While there has been adequate theoretical work linking deep structure noticing and transfer, there hasn't been as much empirical work showing a connection between student's ability to notice deep structure, and their transfer performance. These results suggest that noticing the deep structure of the task is important for transfer.

Practical Implications. The beginning of this paper posed how engineering design activities might move beyond "arts and crafts" tasks to actively engage students in learning and transfer processes. This study suggests found that framing engineering design tasks with learning goals is a key way to support students, so that they value provided resources and transfer. Many engineering design tasks are framed with outcome goals, which focus students on producing some intended result. However, this work suggests that these tasks should be re-framed as learning tasks in order to be more effective.

This is especially important because engineering design tasks are at risk of turning into fun activities that effectively engage students, yet fail to teach them science content. The many reports of students failing to deeply reflect on science content during engineering design tasks may reflect this problem. Engineering design curricula often boast that they improve students' interest in engineering (Brophy, Klein, Portsmore, & Rogers, 2008; Schunn, 2011; Svarovsky & Shaffer, 2007) or improve student intrinsic motivation. However, this may be happening at the expense of students understanding the importance of the learning objectives for the task. Such a move is flawed. Engineering design tasks should be reinforcing learning goals instead of hiding them from students, if the intention is for students to transfer from these tasks.

Limitations

There are some limitations to these studies that warrant the need for further research. First of all, generalizability of findings was hurt by the fact that both studies used advanced science students. The majority of students in study 1 belonged to the school's engineering program, which students need to apply for and be accepted into. Students in study 2 belonged to the school's advance science track. Therefore, future work should see if these findings replicate with students who are not selected into advanced science programs.

Secondly, the resource value questionnaire is a self-report measure, which can have flaws because students often are not very metacognitive, and therefore typically fail to effectively evaluate how helpful something actually is to them. These self-report measures are therefore less reliable than things like posttest measurements, which assess students' actual knowledge and ability, not just students' perception of that knowledge and ability. Therefore, analyses including these measures should be considered with caution. Future work should measure actual student resource use to see if resource use depends is affected by the task goal. Qualitative work should also look at how students are using these resources in a way that aids their learning.

Finally, this study failed to identify a mechanism for how learning goals improved transfer performance. Although noticing the deep structure of the problem did lead to better transfer, learning goals did not improve this deep structure noticing. A more sensitive measure of deep structure noticing may have been needed to detect this effect. Future work should investigate this relationship between learning goals and deep structure noticing or consider what other factors other than noticing may have lead learning goals to improve student transfer. For example, Chapter 3 of this dissertation suggest that it is the ability of student to focus on the deep structure over time, rather than just merely notice it, that may lead to transfer. Furthermore, how students work to integrate the deep structure into their building process may be what aids transfer. Future work should explore these relationships.

Conclusion

In summary, learning goals and contrasting cases have impact on how students transfer from engineering design tasks. As engineering design tasks become more and more popular for teaching students science content knowledge, it is important to discern the role of goals and contrasting cases in these types of tasks. However, while researchers have developed engineering design curricula with a wide variety of cognitive scaffolds, few studies focus on how goals affect students' ability to be successful during these types of activities.

After identifying the importance of learning goals on transfer, I propose that hands on tasks should use learning goals that focus students on the science content of a problem. While this goal might not affect students' ability to build more successful constructions or notice the deep structure of the problem, they can direct students to finding more value in learning resources. This work also suggests that students should not be measured on their ability to simply perform well on these engineering design tasks. Rather, students should also be evaluated on their ability to successful take what they have learned and apply it to new problems in new contexts.

We now live in a world where education is not just about students' ability to learn and regurgitate facts they acquire in the classroom. Engineering design activities are important for student development because they have the potential to engage students in meaningful construction processes that can support the learning and application of science concepts. Tasks must in turn support students to transfer these skills to new problems in new domains. Otherwise, these activates are not meeting their true potential of delivering value to students. If we as an educational community want students to really benefit from hands on engineering activities, then students need to be given goals that will direct them through learning processes that will best prepare them to apply what they learn.

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CHAPTER 3: CASE STUDY

Mechanisms of Focusing on Deep Structure: Potential Pathways for Transfer from an Engineering Design Task

Abstract

Transfer is an important outcome of engineering education, but little work has explored how transfer happens both during and from engineering design tasks. This comparative case study investigates these processes. Two pairs of students who were effectively able to transfer from an engineering design task are compared to two pairs of students who were less able to transfer. The pairs' construction process, use of learning resources, and partner dialogue was analyzed to see how pairs attended to the deep structure of the engineering design problem. While literature on transfer suggests that noticing the deep structure is a key process for transfer, this noticing behavior did not significantly differ between high transfer and low transfer pairs. However, high transfer pairs were able to focus on the deep structure of the problem more effectively throughout the task. Focusing mechanisms found in high transfer pairs included developing a joint understanding of the deep structure early, sustaining concentration on that deep structure when looking at contrasting cases, using resources consistently throughout the construction process to identify features and structures, and systematically testing those features to identify their importance. The differences in these processes between high and low transfer pairs imply that scholars should consider the distinction between noticing and focusing when considering how perceptual learning informs transfer.

Two students, Lindsay and Samantha, have been tasked with building a cantilever out of Legos that can stick 10.5" off a table. They have spent some time trying to build a cantilever, but they failed to get it to stick far enough off the table. After looking at some contrasting case examples, they are now given another chance to try and build a successful cantilever. Before the students start building their structure, they look at a reading about center of mass.

Lindsay: "This is what I did last time. Like, there's more weight on that side." Lindsay points an image of a broom on the reading.

Samantha: "We should put more weight here." Samantha points to the center of the surface they are trying to balance their cantilever off of.

Introduction

The vignette above shows the process of two students, Lindsay and Samantha, who are attempting to bridge concepts between a reading about science principles and their building process, as they try to design a cantilever to solve an engineering challenge. The students know that the reading can help them build a more successful cantilever, and they try integrating this information into their building process. However, this kind of behavior can be rare.

There has been a longstanding trend in modern education practices of engaging students with hands-on construction tasks like engineering design challenges, in attempt to teach math and science principles in science museum exhibits (e.g. Carlson & Sullivan, 1999; Gentner et al., 2016; Zacharias, 2014) and K-12 classrooms (e.g., Kolodner et al., 2003; Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004; Silk, Schunn, & Cary, 2009). These activities often include resources about science concepts, that students are intended to use to inform their designs (e.g., Fortus et al., 2004; Kanter, 2010; Kolodner et al., 2003; Silk et al., 2009).

However, getting students to actually learn science concepts from these learning resources and then apply them to the design task is difficult. Instead, students commonly spend too much time on the construction process, and not enough time thinking about or reflecting on the science concepts that can make their design successful (e.g., Gertzman & Kolodner, 1996; Hmelo, Holton, & Kolodner, 2000; Kanter, 2010; Roth, Tobin, & Ritchie, 2001; Silk, Schunn & Cary, 2009; Vattam & Kolodner, 2008), which can in turn hurt a student's ability to effectively learn science concepts from the engineering design activity (Worsley & Blikstein, 2014).

This case study investigates how and why students are able to transfer knowledge between contexts within the engineering design task and transfer knowledge from the task to solve different problems later. I refer to the former process as "transfer within". This term is a conglomerate of Schwartz and Martin's (2004) "transfer in" and "transfer out" processes, which occur often during engineering design tasks, as students try to connect concepts across many different resources and contexts. I contrast "transfer within" with the process of transferring knowledge from the entire construction activity, to solve new problems in new contexts later—such as performing well on a pencil-and-paper physics test. In this paper, I refer to this kind of transfer as "transfer from".

This case study investigates what leads to successful transfer within and transfer from complex engineering design tasks. I consider the role of noticing and focusing on deep structure as the main processes by which these kinds of transfer happen.

Noticing and Focusing on Deep Structure for Transfer

The fact that students are typically unable or unwilling to take conceptual knowledge from a resource, and apply that knowledge to a construction task is largely a transfer issue. In a noticing view of transfer, where transfer is dependent on students' ability to effectively notice the invariant structure across contexts (à la Greeno, Moore, & Smith, 1993), these kinds of failures could be due to students' inability to notice the deep structure of the science content that bridges the reading and the construction task.

This theory is based on work by Greeno and colleagues (1993), who argue that transfer is dependent on a student's ability to notice the affordances and constraints that are congruent across learning and transfer contexts. Students who are able to successfully transfer across contexts, first effectively notice the affordances of both the learning and transfer context, and then are able to act similarly, and appropriately in accordance with the affordances of those varied contexts. Perceptual theorists claim that student develop the ability to act in accordance with situational affordances by "picking up" information (Gibson & Pick, 2000). Exploratory pick up helps students identify what to notice, and performatory pick up reinforces how students are using what they notice in accordance with their environment. In turn, students need to "learn to perceive" by improving their perception over time, and "perceive to learn" by using that improved perception to perform better (Pick, 1992). I argue these processes also help students transfer, better.

Yet while this work describes *how* noticing occurs, theorists have also considered the importance of *what* students notice. Specifically work suggests that successful transfer is dependent on a student's ability notice a deep structure, and to know how to act in accordance with the presence of that deep structure (Schwartz, Chase, Oppezzo, Chin, 2011; Greeno et al., 1993; Lobato, Rhodehamel, & Hohensee, 2012). For these reasons, I discuss noticing as a student's ability to both perceive and know how to work with, certain information in a context.

This is also evident in empirical work. For example, in a famous set of studies by Gick and Holyoak (1983), students are tested on their transfer ability during a task in which they have to take a principle (the deep structure) from one problem and effectively apply it to solve another problem. Task modifications that helped students both notice the deep structure (e.g. giving them a second scenario to improve perception of the underlying principle) and how to apply it (providing a hint that the first problem solution can be used to solve the second problem) improved transfer performance.

I argue however, that while the transfer literature notes the importance of noticing deep structure, it should also consider how students attend to that deep structure over time and determine its importance in the context of various problems. I call the latter process focusing. For this paper, noticing is considered the ability to perceive and work with select information at any given point in time, while ignoring other information. This definition is in accordance with Lobato, Rhodehamel and Hohensee's (2012) definition of noticing, which describes noticing as "selecting, interpreting, and *working with*" (p. 438) certain information in the presence of other factors that could compete for students' attention. In contrast, I define focusing as the ability to deem noticed information as important for task success, and choose to engage with that information over time. For example, to successfully transfer, students need to first recognize certain task features and know how to apply that information to a problem or task (noticing). Yet, even when students notice important or relevant information they can always then shift their attention to other, irrelevant information. For example, work by Carraher and Schliemann (2002) has shown that even when students seem to be "failing" at transfer, they are still transferring in information. It's just that the information they are transferring may not be relevant for task success. Therefore, to ensure successful transfer, students need to choose to engage with relevant task features consistently during problem solving, while confirming the importance of these features (focusing).

While work has explored the mechanisms by which students notice (e.g. Goodwin, 1994; Lobato et al., 2012), I am not aware of any work that has considered the mechanisms by which students focus. Specifically, little work has looked at how noticing changes over time, and how these changes affect a student's ability to determine the significance of the deep structure of a problem. Yet focusing is important, because transfer is hard, and students' conceptions can be fickle. If the aim of engineering design activities is to engage students in thinking deeply about scientific principles and how to employ those principles thoughtfully in their designs, we first need to understand how students might choose to engage with these principles over time. Then we must understand how students determine the relevance of these principles to the construction task. This is especially important during complex tasks where student's attention can be captured at any time by resources, peer ideas, or the intrigue of the building task. Therefore, I posit that transfer success within hands-on engineering design tasks requires students to not only notice but also *focus* on the deep structure throughout the task. And yet, we don't know how this focusing might happen during such an activity.

The Present Research

The following case study aims to investigate how students both notice and focus on the deep structures of a problem, while working on an engineering design task. It aims to understand how noticing and focusing processes differ between students who are able to successfully transfer, and students who are less successful. Furthermore, considering claims that noticing is affected by a multitude of factors including language, the objects students work with, and students own cognitive processes (Greeno et al., 1993; Lobato et al., 2012), this case study aims to understand how these factors affect noticing and focusing processes.

Method

Procedure & Materials

This investigation is a secondary analysis of video data that came from a larger project on the role that contrasting cases and task goals have on students' ability to learn conceptual science principles and transfer them from an engineering design task. The study was a week long, and comprised of a pretest, the engineering design activity, an instructional lecture, and a posttest.

The purpose of the learning unit was to teach students about center of mass. To learn this concept, students were given an engineering design task, which they did in pairs. The task was for each dyad to build a freestanding cantilever that can hang 10.5" off the edge of a table using Legos (for example of student cantilevers, see Figure 8).

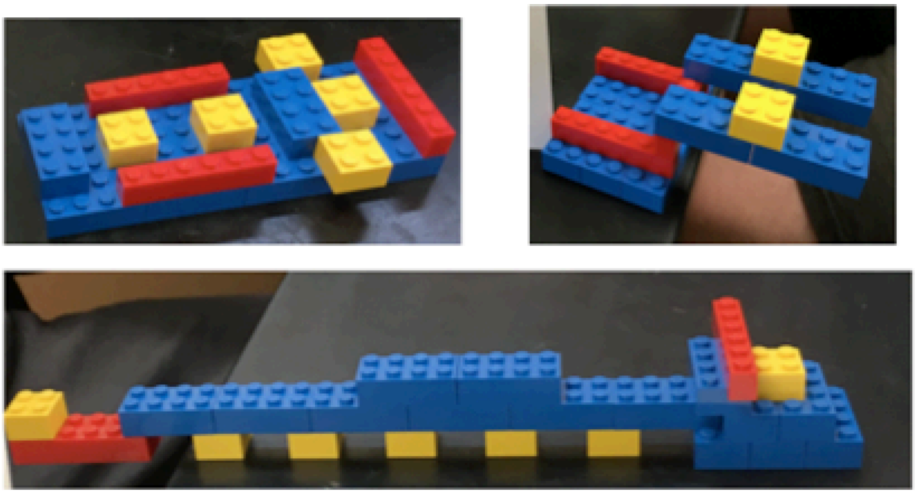

Figure 8. Examples of student cantilevers from the engineering design activity.

Center of mass is a weighted average (Figure 9). For this challenge, each Lego acts as a point mass, and the distance each Lego is placed from the center of the cantilever (x_i), along with each Lego's weight (m_i), over the cantilever's total weight ($\sum m_i$) affects the location of the center of mass ($X_{\text{center of mass}}$) within the cantilever. Furthermore, a cantilever can balance just by resting on its center of mass. Therefore, to complete the challenge, a participant's cantilever has to optimize the placement of each Lego, by distributing the large Legos as far back as possible, so that the center of mass of the cantilever is as far onto the table as possible. Only then will the cantilever balance while extending 10.5" off of the table.

$$X_{center\ of\ mass} = \frac{m_1x_1 +\ m_2x_2 + \ldots + m_nx_n}{m_1 +\ m_2 + \ldots + m_n} = \frac{\sum m_ix_i}{\sum m_i}$$

Figure 9. Equation for center of mass

For example, below is the ideal cantilever for this challenge (Figure 10). The best possible cantilever is a straight line because to move the center of mass as far onto the table as possible, the students have to put as much weight as far back as possible. Putting more weight in the back or putting the weight further back, moves the center of mass further back, which allows the cantilever to stick off the table more. If students had infinite Legos, they could increase the weight of the back by stacking Legos at the back of the cantilever until it was heavy enough to pull the center of mass 10.5" onto the table. However, since there is a limited number of Legos, the mass of the cantilever is fixed. So the only way to change how much each Lego pulls the center of mass back is by placing that Lego further back in the cantilever. Students therefore often fall into the misconception that putting a tall tower at the back of their cantilever will increase the "weight" of the back and make their structure stick off more. Similarly, students tend to make the back of the cantilever wider, to increase the "weight" there. However, these strategies only concentrate weight in one part of their cantilever. To be successful, students have to realize that the only way to move the center of mass is to distribute this weight back, which maximizes the distance at which each Lego is placed. The optimal distribution of the weight is therefore a straight line.

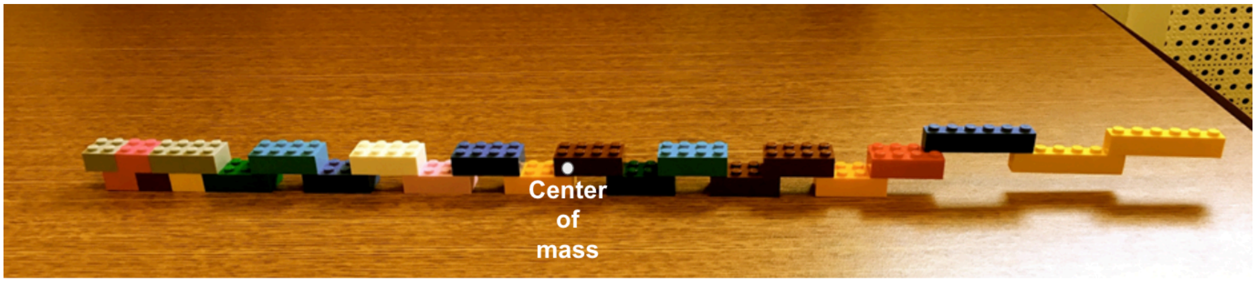

Figure 10. Ideal cantilever.

As part of the larger study, each student was assigned a different goal during the engineering design task. Half the students were randomly assigned an outcome goal, which was to, "build a structure that can stick 10.5" off of a table". The other half of the students were given a learning goal, stated as —"Figure out a **rule** that indicates where a structure's balance point is. Make sure your rule explains why some structures stick out more than others." Students with the learning goal were told that if they identified the correct rule, it would tell them how to build a cantilever that could stick 10.5" off the table. The task was framed as a way for these students to test the quality of their rule (for full task sheets, see Appendix B). The ideal rule would be a verbal approximation of the relationship between mass and distance found in the center of mass equation. For example, an ideal rule might read, "An object's center of mass is determined by both weight, and the distance at which that weight is placed. So if there is more weight on the table, or if that weight is placed farther back onto the table, the center of mass will move farther onto the table, and the structure can stick out more".

Students performed a series of activities as part of the engineering design task (Figure 12). They had two building periods to work with the Legos as they tried to reach their assigned goal. During each build, students were given a textbook on which they could place their cantilever. To test their cantilever, they were told to move their construction off the textbook until it was about to fall, and then measure it with a provided ruler. During both builds, students were also given notes sheets that prompted them to keep track of how close they were to reaching their goal. After each build period, students evaluated how effective their builds were. They were given a sheet that asked them how close they were to reaching their goal, and what they learned during the previous build period.

Between the two build periods, students were given two sets of contrasting cases to reflect on (Figure 11). Contrasting cases are examples that differ on key features, to make certain variables or relationships more salient to learners (Bransford & Schwartz, 1999). For example, tasting glasses of wine side by side would make it easier to notice differences in each wine's flavor profile. Work has shown that use of contrasting cases in instructional activities aid students deep feature noticing, which in turn improves transfer (Aleven et al., 2017; Bransford, Franks, Vye, & Sherwood, 1989; Chase, Harpstead, & Aleven, 2017; Roll, Aleven, & Koedinger, 2011; Schwartz, Chase, Oppezzo, Chin, 2011; Shemwell, Chase, & Schwartz, 2015). In this activity, students first reflected on a set of yellow cases, which were explicitly designed to highlight the key relationship between mass and distance when calculating center of mass. This will be referred to as reflection 1. During reflection 2, students then reflected on a set of red cases that addressed common student misconceptions, such as whether the height or the width of the cantilever matters. During these two contrasting case reflections, students filled out a worksheet that asked a series of questions, requiring the to draw specific comparisons between the various cases. These questions were designed to help draw students' attention to what caused certain cases to stick out more than others, and therefore notice the deep structure.

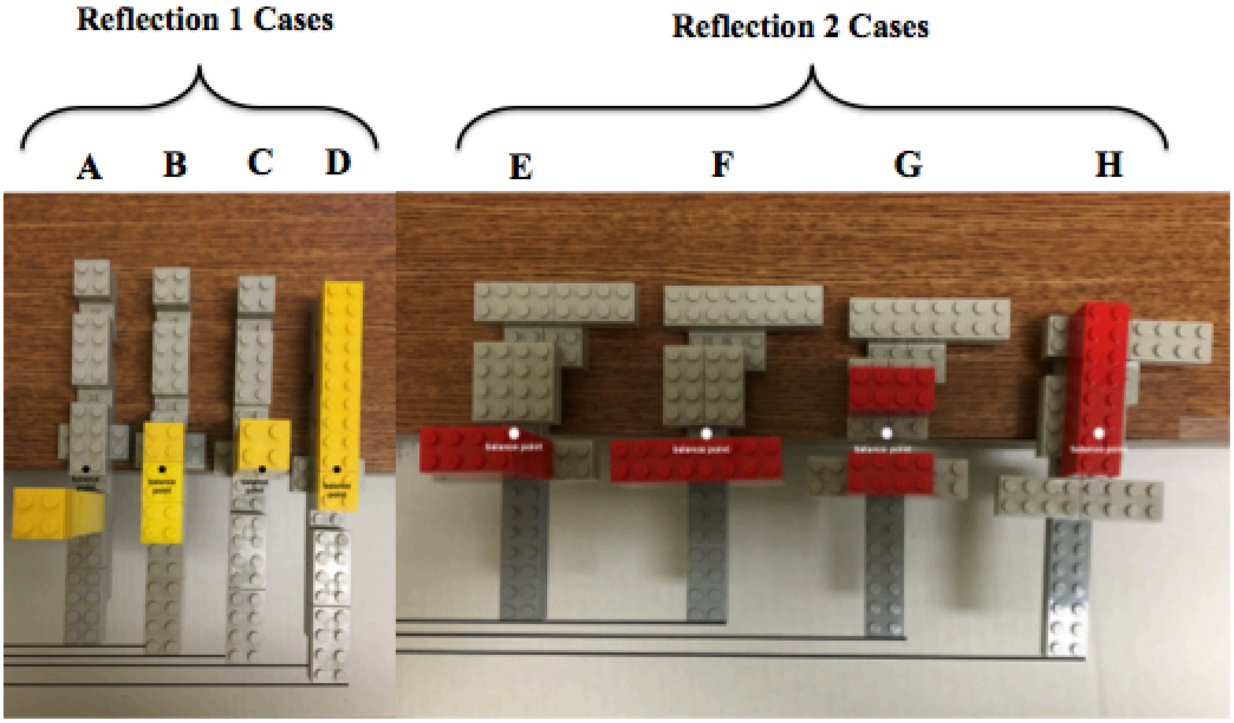

Figure 11. Contrasting cases presented in reflection 1 (left) and reflection 2 (right).

During build 2, which took place after the case reflection, students were given a single page textbook style reading on center of mass, and images of the contrasting cases, which they could reference as they pleased throughout the build period. After the engineering design task, students were given a lecture on center of mass, and a transfer test that assessed students' ability to apply center of mass concepts to a variety of novel problems in novel contexts.

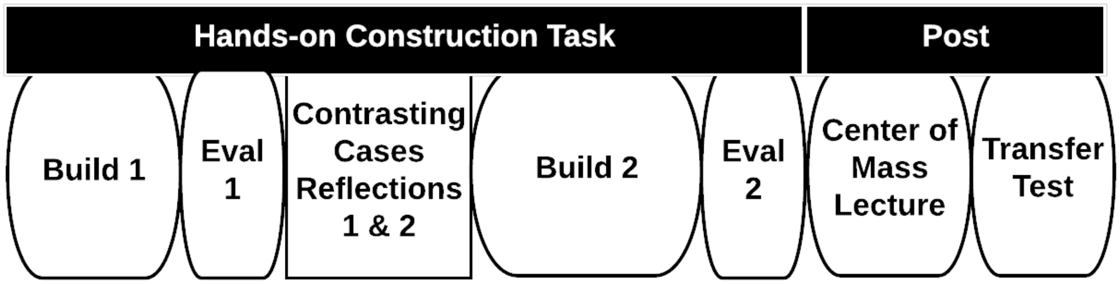

Figure 12. Study design.

Participants

Participants were eight students from a suburban public high school in the Mid-Atlantic United States. The school population was 11% White, 2% Black, 84% Hispanic, and 3% Asian, with 72% of the student body receiving free or reduced lunch. The school ranks in the 25th percentile in its state's test scores. Students participated in the study during their usual science class.

Four pairs of students were analyzed for this study. The first pair, Marc and Jennifer (all student names used in this study are pseudonyms to protect student identity), was a high transfer pair assigned an outcome goal. The second pair, Lindsay and Samantha, was another high transfer pair but they were assigned a learning goal. The third pair, Padma and Raven, was a low transfer pair assigned an outcome goal. Finally the fourth pair, Alonso and Rebecca, was a low transfer pair assigned a learning goal. The two high transfer pairs had the highest combined transfer gain scores from all viable videos in their goal group. Likewise, the low transfer pairs had the lowest combined transfer gain scores from all viable videos in their goal group. However, when looking at students as individuals a high transfer learning goal student (Lindsay) was below average for the class and one low transfer learning goal student (Alonso) was above class average of 38% (Table 15). However, there were no learning goal pairs with viable video data where both students performed above the class average, or both students performed below the class average. Therefore, analysis focused on the two learning goal pairs that were the highest or lowest performing in their group when considered as a dyad.

Table 15

Average Transfer Percent Gain Score for Each Student

Pair	Name	Transfer	Goal	Transfer Percent Gain Score
1	Marc	High	Outcome	66%
1	Jennifer	High	Outcome	42%
2	Samantha	High	Learning	76%
2	*Lindsay	High	Learning	28%
3	Padma	Low	Outcome	37%
3	Raven	Low	Outcome	24%
4	*Alonso	Low	Learning	44%
4	Rebecca	Low	Learning	26%

Note. *All high transfer students had an above average gain score and all low transfer students had a below average gain score with the exceptions of Alonso and Lindsay.

Note that although individual students within pairs had different transfer gains, analyses were conducted at the pair level. This was in part because this case study was investigating in how transfer occurs in situ. Views of situated transfer must take into account not only the individuals, but also resources and tools that comprise that noticing, focusing and transfer process (Greeno, 2004). Other case study work looking at how transfer occurs in groups has noted this situated transfer context required considering the group as a unit rather than the individual (Engle, 2006). In part the group level analysis better considers how common ground (Clark, 1996) is established for the group, which in turn affects what students learn and transfer (Engle, 2006).

In addition to each pair's transfer ability, pairs were chosen based on the quality of their work and the quality of their video data. I chose pairs that had a good amount of consistent dialogue throughout the task, so that I could identify what the students were thinking. Likewise, I focused on pairs who were effective collaborators, and who tried to be successful on the task since they used the resources provided and therefore received all of the intended instruction for this activity. High transfer pairs were also more successful on the build task, having built structures that successfully stuck farther off the table (Table 16).

Table 16

Building Performance (in Inches) by Pair

Pair	Transfer	Goal	Final Structure Length
1	High	Outcome	10.5
2	High	Learning	8.5
3	Low	Outcome	4.0
4	Low	Learning	7.0

Analysis

Student pairs were videotaped during both builds, and the two contrasting cases reflections. That video was analyzed along with the notes students took during each build period, and the evaluations they did after each build period. Although students worked in pairs during the building task and cases reflection, students filled out their notes sheets and evaluations separately. This helped assess what students were individually taking away from their partner.

The goal of this case analysis was to see how the process of noticing and focusing on the deep structure differed between high transfer and low transfer pairs. High and low transfer pairs were analyzed with the intention of uncovering meaningful differences in their noticing and focusing process that might explain what led to differences in their transfer performance. First, videos were viewed to identify *where* interesting noticing and focusing behaviors were present. Next, transcripts were coded to identify *what* students were noticing and focusing on. Finally, transcripts were coded to identify *how* students were going about noticing and focusing.

Where noticing and focusing happen. An initial reading of the cases was used to identify *where* pairs showed interesting behaviors. The main places where noticing happened were in a) partner dialogue b) contrasting case use c) resource use and d) building behavior.

What students notice and focus on. Several analytical passes were then taken through the data, to identify *what* students were noticing and ultimately focusing on. Lobato, Rhodehamel, and Hohensee's (2012) conceptual frame, which considers the "features, regularities, properties, or conceptual objects to which individual students attend" (p.439) was used to inform this analytical pass. This analysis accounted for what features and structures students attended to during the task. Features are defined as a single element that a student could attend to, such as mass, height, or distance. Structures were defined as a relationship between several features, such as considering the relationship between mass and distance. The "deep structure" of the task was the multiplicative relationship between mass and distance, since this relationship was both tied to the canonical science principle being taught (center of mass) and was the key to solving the challenge activity (distributing weight back). After my own analytical look at the data, I identified six major features and structures that students attended to during the activity (Table 17).

Table 17

Codes Used to Identify What Students Attended to During the Task

Name	Kind	Level	Description	Example
Mass	Feature	Deep	Noticing weight is important	"We could add, more weight to this one."
Distance	Feature	Deep	Noticing length or that the distance between Legos is important	"We have to make it longer"
Greater mass back	Structure	Deep	Noticing that as both the mass and distance, increase the center of mass moves back	"Yeah maybe like that it's heavier and really long"
Height	Feature	Irrelevant	Noticing that height is important	"Ok, I'm going to like... make it tall"
Width	Feature	Irrelevant	Noticing that width is important	"Then I can make this even wider if you wanted to."
Greater Mass Middle	Structure	Irrelevant	Noticing that as both the mass and distance, increase the center of mass moves back	"They all have something in the center, like I wanted to do."

I then categorized each of these as either "deep" or "irrelevant". Deep features are features of the task that relate to the actual center of mass equation, the underlying principle of this task. For example, mass and distance are deep features because they are distinct components of the center of mass equation. Irrelevant features are features of the task that can lead to some success on the task, but do not directly relate to components of the center of mass equation. For example, for the irrelevant structure “mass middle” many students are thinking about the relationship between mass and distance, but in a way that doesn’t effectively move the center of mass. Other irrelevant features hit upon common student misconceptions, such as height or width. The deep structure of the problem is the multiplicative relationship between mass and distance. When applied to the problem, this deep structure indicates that increasing the mass in the back of a cantilever or increasing the distance at which each Lego is placed moves the center of mass back more.

Codes were based on both student dialogue and gestures, as these two interacted to determine what students attended to. For example, if a student said, “put the weight here” and pointed to the back of their cantilever, then that was coded as “greater mass back” (deep structure) but if they pointed to the middle of their cantilever then it was coded as “greater mass middle” (irrelevant structure).

Noticing and Focusing. Once the main features and structures of the task were identified, I looked to see *how* students went about noticing and subsequently focusing on the deep structure. I used both a bottom up and a top down approach to see what behaviors led to student noticing. Taking a top down approach, I considered discourse practices identified by Goodwin (1994) as well as interactions identified by Lobato and colleagues (2012). In a bottom up approach, I looked at how students were noticing various features and structures during the task, paying special attention to behaviors that seemed to distinguish the practices of high and low transfer pairs. Ultimately six processes of noticing were identified in the data: highlighting, clarifying, honing in, comparing & contrasting, demonstrating, referencing and testing (Table 18). The concepts of highlighting and demonstrating come from Goodwin's (1994) work on professional vision. I expand Goodwin's definition of highlighting to include not just physically marking something to make it salient, but also naming, gesturing and other means of directing attention. As for demonstrating, I again expand Goodwin's definition from just "producing and articulating material representations" to mean any representation created by a student for the purpose of demonstration. The comparing and contrasting mechanism came from literature on the role of these behaviors in helping students notice (Marton, 2006; Schwartz & Bransford, 1998). The other four mechanisms—clarifying, honing in, referencing and testing—are new to this analysis. Clarifying referred to when students took measures to make sure they and their partner were in joint agreement about what a feature or structure meant. Honing in, occurred when students would continue to notice a feature or structure, even when presented with new information. Referencing described when students looked at, pointed to, or discussed a learning resource. Finally, testing referred to when students measured their cantilever to see how far off the table it went.

Table 18

Codes Used to Identify Noticing Processes

Process	Description	Example
Highlighting	Directing attention by gesturing or naming.	A student talks about length to get his partner to notice that feature.
Clarifying	Student continues to discuss, highlight, or demonstrate something that has been noticed in the face of partner confusion.	Marc: "what do you mean?" Jennifer: "Like that". She points to the back of case D.
Honing In	Attending to the same feature or	Looking at first set of cases, "I think

	structure even when new information is provided or another feature is highlighted.	it’s distance and weight.” They then get the second set of cases. “It’s the same.”
Comparing & Contrasting	Attending to two examples and describing similarities and differences between them.	Looking at two cases and recognizing that they both have weight in the middle.
Demonstrating	Using gesture, drawings, or construction behaviors to direct attention to a feature.	A student makes a tower on the back of the cantilever to demonstrate what she means by “add weight”.
Referencing	Looking at, pointing to, or discussing something in a learning resource, such as the center of mass reading.	“Yeah. ‘Cause look.” Student picks up the center of mass reading and points to it.
Testing	Any time a student held up a ruler and looked at it to measure how far off the edge their cantilever could hang.	“We’ll have to measure it.” Student measures cantilever.

Once transcripts were coded I then looked at what students attended to, how they went about noticing, and where these processes occurred. Findings were organized in a matrix (á la Miles, Huberman, & Saldana, 2014) to make large patterns discernable (Table 19). This matrix suggested that what students noticed and how students went about noticing did not differ between the four pairs. However, how students went about focusing on the deep structure did seem to differ between high and low transfer pairs. These differences signaled the presence of four focusing mechanisms, or ways that high transfer pairs attended to the deep structure over time and determined its importance. These focusing mechanisms are described in the results section below.

Results

Behaviors Common to All Pairs

It’s important to first note which behaviors were common to all pairs, regardless of transfer ability. First, all students were engaged in the task. All four pairs put in considerable effort, and worked together (e.g. collaborated) effectively during the instructional activities. Therefore, it is highly unlikely that any differences in transfer ability between groups were due to student effort or quality of pair collaboration.

Furthermore, what students noticed during the activity did not significantly differ between pairs. In general, all pairs noticed deep and irrelevant features and structures. Furthermore, all four pairs were able to notice the deep structure in both build periods, the contrasting cases, and an instructional reading provided during the second build period. Therefore it didn't seem like what features students noticed, affected the various pairs' transfer ability.

Next, all pairs used provided resources with intention. All four pairs thought deeply about the contrasting cases to notice the deep structure by comparing and contrasting between cases. All four pairs also used the cases to address misconceptions. For example, the high outcome pair noticed height and the low transfer outcome pair noticed on mass middle during the first build. Both of these pairs then realized that these features were misconceptions after looking at the contrasting cases. During the second build period, all four pairs referenced both the center of mass reading and the contrasting cases while building.

Finally, analyses failed to identify any significant differences between pairs with a learning goal and pairs with an outcome goal. For this reason, although I identify pairs by their goal condition in the rest of the analyses, I do not discuss any effects of goal condition.

Focusing Mechanisms

The similarities listed above suggest that what students noticed didn't seem to affect transfer. Instead, the real difference between high and low transfer pairs seems to be that high transfer pairs developed greater focus on the deep structure over the course of the activity.

There were several ways in which students went about focusing on the deep structure. First, high transfer pairs developed a joint understanding of the deep structure early, during the first build. They then concentrated on this deep structure more during the contrasting cases reflection. In the second build, they then referenced learning resources to identify deep and irrelevant features to test. This testing in turn may have helped high transfer pairs confirm that the deep structure was important, and to disconfirm the importance of irrelevant features.

In contrast, even though low pairs noticed the deep structure during the first build, they failed to finish the building period with a joint understanding of the deep structure, or its importance to the task. Low transfer pairs then failed to concentrate on that deep structure during the contrasting cases reflection. During the final build, low transfer pairs infrequently referenced learning materials and infrequently tested. Furthermore, they built copies of examples from the resources instead of integrating features from the resources into their designs. These behaviors in turn may have prevented low transfer pairs from identifying the significance of the deep structure of the task, even though they noticed it periodically throughout the activity.

Table 19

Matrix of and Focus Noticing Mechanisms Across High and Low Transfer Pairs

When	Transfer Level	Where	Noticing Processes	What	Focusing Mechanisms
Build 1	High	Build Talk	Demonstrate Highlight, Clarify	Deep structure	Joint understanding of the deep structure

	Low	Talk	Highlight	Deep structure	Disjointed understanding of the deep structure
Contrasting Cases Reflection	High	Cases Talk	Compare & Contrast, Highlight, Demonstrate, Clarify, Hone in	Deep structure	Sustained concentration on deep structure
	Low		Compare & Contrast, Highlight, Demonstrate, Clarify	Deep structure	Interrupted concentration on deep structure
Build 2	High	Resources Talk	Reference, Highlight	Deep & Irrelevant Features	Use resources to identify which features & structures to test
	Low		Reference	Irrelevant Structure	Use resources to identify examples to copy, fail to identify features
	High	Build Talk	Test	Deep & Irrelevant Features	Systematically test to identify which features are important (and not)
	Low			Unknown	Infrequent testing to identify if cantilever is successful

Establishing joint understanding of the deep structure. The first key difference between high and low transfer pairs is that during the first build, high transfer pairs were able to focus on the deep structure more by establishing a joint understanding of it. For example, in the high transfer learning pair, Lindsay notices features of mass and distance but her partner Samantha is not able to successfully incorporate these features into their cantilever. Lindsay then demonstrates what she means to clarify her point. This allows the pair to come to a joint understanding of the deep structure. (Note that all excerpts in the following have italics and annotations added to emphasize these noticing processes).

Excerpt from High Transfer Pair:

Lindsay: Measures cantilever.

Samantha: "How long is it?"

Lindsay: "See? It's not gonna, no." She measures the cantilever while holding it up with her hands. *"So I have to put maybe more **weight** there?" She points to the back of the cantilever.* [*highlighting deep feature*]. Samantha moves some Legos farther back in the cantilever. "Or…" Samantha lets go of the cantilever and it falls off the book.

Samantha: "Like that. Nah?"

Lindsay: "Ok". Samantha takes Legos from the back and moves them a bit more forward. *"What if I add like more of these…" Lindsay points to the yellow Legos, "to the back and these…" she points to the red Legos, "to the…" She points to the front of the cantilever. [clarifying by demonstrating deep feature]*

Samantha: "*Yeah because they don't weigh a lot.*" [*clarifying*] Samantha takes the red Legos off the back of the cantilever.

Here Lindsay first *highlights* the deep structure of greater mass back. She both names it ("So I have to put maybe more weight there?") and points to where she means, in order to make sure that Samantha can appropriately attend to this feature. Samantha then attempts to instantiate Lindsay's idea into the cantilever, but she starts to move weight forward instead of back. To clarify her point, Lindsay first demonstrates what she means by weight. She points to the heavier yellow Legos and dictates that they should be in the back, while the lighter red Legos should be in the front. Now Samantha better understands what Lindsay meant by "weight" back. This demonstration also makes it clear that not only should the heavier weights be in the back, but also the lighter weights should be in the front. This is a sophisticated understanding of the greater mass back principle, because it shows that Lindsay understands that having greater mass in the back requires the mass in the front of the cantilever to decrease. Due to this demonstration, Samantha now has a better understanding of what Lindsay meant by “more weight there”. She confirms this understanding through dialogue (“Yeah, because they don’t weigh a lot”) before continuing to build out the cantilever as Lindsay had intended.

In this way the high transfer pair works together to clarify their understanding of the deep structure. This demonstration and clarification are important for the pair to develop this joint understanding. A similar process happens in the high outcome pair. Early on, Marc notices the deep structure. However, his partner Jennifer does not understand what he means by greater mass back. Through answering questions to clarify, and building together to demonstrate their intentions, the pair comes to a joint understanding of the importance of putting more weight in the back, and less weight in the front.

In contrast, the low transfer pairs develop a disjointed understanding of the deep structure, even though they notice it. This disjointed understanding may be attributed to the fact that the deep structure is not demonstrated or clarified by either student.

Figure 13. Build 1 cantilever for the low transfer pair. The front of the cantilever is considered the part on the left, which is lined with red Legos on the bottom. The back of the cantilever is considered the part on the right, with yellow Legos on the bottom.

Excerpt from Low Transfer Pair:

Alonso: “OK. So then this can go here.” He finishes adds a yellow Lego to the front with the red Legos [where the hand is in the Figure 13 photo above].

> **Rebecca:** “There I go.” Alonso picks up the cantilever.
>
> **Alonso:** “OK”
>
> **Rebecca:** “Can I make this part ***weigh***…” She points to ***the back of the cantilever***, and then points ***to the top of the book***. [*highlighting deep features of mass and distance*] “Should I try?” She puts the cantilever on the book. “Oh my god. I'm so scared.”
>
> **Alonso:** “I don't know where the half point is though.” He moves cantilever off the book until it tips. “Would it be at...?” He moves cantilever and it starts to tilt off the book.
>
> **Rebecca:** “Ooh.”
>
> **Alonso:** “Ok, hold on, maybe let's do it the other way.” He rotates the cantilever 90 degrees. The front of the cantilever is still hanging off of the book, but it’s coming off a different edge of the book.
>
> **Rebecca:** “***More weight here or something***?” *She points to the back of the cantilever.* [*highlighting the deep structure*]
>
> **Alonso:** “Yeah.” Rotates the cantilever so the yellow, heavier part is now off the book. He again pushes the cantilever until it's about to fall.
>
> **Rebecca:** “Ohh.” The cantilever tilts. “Op!”
>
> **Alonso:** “Where's the middle, though?”
>
> **Rebecca:** “The goal is 10.5” She tries to measure the cantilever while Alonso holds it. The build period then ends.

In this scene, Rebecca uses naming and pointing to highlight the deep structure of greater mass back. However, she never demonstrates or clarifies what she means. As a result, Alonso misunderstands her. Rebecca brings up the feature of greater mass back, but fails to properly name it (“Can I make this part weigh…”). She does gesture to the back of the cantilever, but she doesn’t mention that weight has to increase there. Meanwhile, Alonso attends to other things. When Rebecca does effectively highlight the deep structure (“More weight here or something?” She points to the back of the cantilever), Alonso does not connect that mention of greater mass back to the idea of adding more Legos. Instead, he rotates the cantilever so that the lighter part is now on the table. At this point Rebecca fails to clarify what she means, even though it is evident that Alonso misunderstood her. As a result, by the end of the build period, the pair does not have a common understanding of where the weight should be in their cantilever, or potentially what the term weight even refers to. By failing to demonstrate or clarify the deep structure, they have also failed to develop a joint understanding of it. Consequently, the low transfer pair fails to focus on the deep structure.

The difference between low transfer and high transfer pairs is evident by the end of the build period, when students are asked to write down what rule they came up with and what they learned (Table 20). The low transfer pair's responses fail to mention the deep structure. Only Rebecca mentions weight, in her evaluation, and even then she is not able to articulate how weight is important. Meanwhile, the high transfer pair's responses consistently note the importance of the deep structure. Both students mention the significance of greater mass back. This suggests that the deep structure that they noticed and discussed during the building task was similarly understood, and could be effectively abstracted and communicated in a consistent way outside of the task.

Table 20

Build 1 Evaluation Responses from High and Low Learning Goal Students

Transfer Level	Name	What is your rule?	What did you learn during the build period that helped you reach your goal?
High	Lindsay	Add weight on the table	What helps to balance an object off a table

High	Samantha	That it should weight more on the table	That adding weight to the structure on the table helped it to not fall
Low	Rebecca	Our rule is to make sure the structure is far as possible	It take a while and takes a lot of patience to reach the goal, and weight is an important factor here and communication is a must
Low	Alonso	Our rule is to make the structure as far as possible than others	It's much harder than it looks. Trying to assemble something with a goal can be very intimidating. Communication is key though. With a partner, it's much easier with a partner.

Similar behavior can be found in the outcome goal pairs. Both students in the high transfer outcome pair mention the importance of weight during their end of build evaluations. In contrast, students in the low transfer outcome goal pair wrote during the evaluation that they “learned nothing” from the first build. Even though the low transfer outcome goal pair did notice the deep structure twice during the first build, the students neither demonstrate nor clarify what they mean. Instead they spend time attending to how to attach the Legos without the cantilever breaking.

In this way, the high transfer pairs are able to focus on the deep structure during the first build, by developing a joint understanding of that deep structure. Both high transfer pairs seem to come to this joint understanding by demonstrating and clarifying what they think the deep structure is after noticing it. In contrast, both low transfer pairs notice the deep structure of greater mass back, but fail to focus on it. As a result, they end the build period with a disjointed understanding of the deep structure and its importance.

Sustained concentration on the deep structure of the contrasting cases. After the first build, all students look at contrasting cases, meant to help them notice the deep structure. For all four pairs, the first set of cases help them notice this deep structure and recognize how cantilevers that stick out more, have more weight placed farther back. For some pairs, the cases also help the students address misconceptions.

Still, high and low transfer pairs differ in their ability to *focus* on the deep structure during the contrasting cases reflection. High transfer pairs notice the deep structure during the first set of cases, and then hone in on it when they see the second set of cases. Honing in allows high transfer pairs to sustain concentration on the deep structure while reflecting on the second set of cases. This in turn helps them focus on the deep structure more during the contrasting case reflections. Yet, even though low transfer pairs also notice the deep structure in the first set of cases, they fail to hone in on that structure. As a result, during the second set of cases, low transfer pairs interrupt their concentration on the deep structure by frequently attending to different, irrelevant features. Ultimately, this lack of sustained concentration prevents the low transfer pairs from focusing on the deep structure.

During the first case reflection, there are not large differences between high and low transfer pairs. All four pairs carefully compare and contrast the first set of cases, then highlight, demonstrate and clarify what they are seeing to ultimately notice the deep structure of weight back. For example, the high transfer outcome pair starts by discussing irrelevant features like the base, the shape, and the number of Legos in each case. Then Jennifer asks Marc what he notices about the cases that stick out most.

Excerpt from a High Transfer Pair:

Marc: "It had most of the, more weight in the back." He circles the yellow blocks in D again. "Most of the weight in the back."

Jennifer: "It does?"

Marc: "Yeah like back of it." He uses hands to section off the back half of cantilever D. "This is the front," he motions to just the grey part sticking off the table. "*...has more like weight more mass," he motions to yellow parts in the back*. [*demonstrating deep feature and clarifying*]

Jennifer: "But this one doesn't have most of the weight here." [*contrasting with another case*] She points to the back of cantilever A. [*showing confusion*] "Some, *most of the weight here*." She points to the tower in the middle of A. [*highlighting irrelevant structure*]

Marc: "Yeah, and it's much shorter." He uses his finger to make motion from D to A. [*contrasting cases*] "You get what I mean? The one that sticks out the most," he delineates the yellow blocks in the back of cantilever D, "has a lot of the weight." [They continue to argue for a while. Jennifer argues that all the cantilevers have weight in the middle, while Marc focuses on the weight being back in the cantilevers that stick off more.]

Marc: "Okay so my idea that I have for the rule is *the center of mass will be closer to where most of the mass is*." [*clarifies deep structure*] He uses his hands to gesture a space in the middle of the cantilever that he then moves his hands back, further onto the table. "Like, like you know what I mean? Like here the center of mass in these two is really close." He points to the center of mass on cantilevers A and C [*comparing cases*]. "But you get...uh, I don't know how to explain this. This is the stake right?" He delineates all of cantilever A with his two hands. "The center of mass like almost in the middle," he points to the center of mass in the middle of cantilever A, "and the center, like most of the weight is spread out evenly." He has his hands in the middle of the cantilever on the center of mass and then *separates his hands across the cantilever with one hand going off the table and one hand going farther onto the table*. [*demonstrates and clarifies deep structure*]

Jennifer: "Alright." [They then discuss how to word their rule].

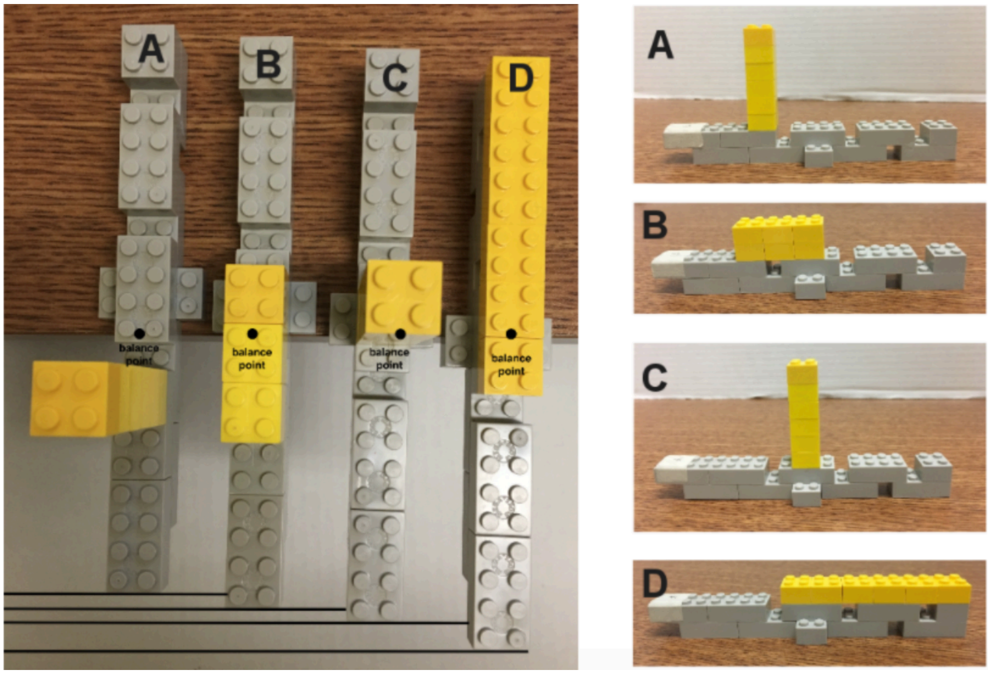

Figure 14. First set of yellow cases, presented to students during reflection 1. Each student had a color photo of these top and side views of the cases, as well as physical versions of these cases, which were shown in the classroom.

This dialogue demonstrates how students typically came to notice the deep structure. The pairs started off by considering some irrelevant features. But after being asked what is the same about the cantilevers that stick off the most, Marc realizes through the process of contrasting the given cases that the cantilevers with weight farther back stick off more. However, his partner Jennifer is focused on the irrelevant structure of weight middle. She demonstrates what she means by showing Marc what she thinks is a counter case (“but this one doesn't have most of the weight here”). Marc then continues to clarify and demonstrate what he means by comparing across cases, and using hand gestures to help highlight weight on the table versus off the table. This demonstration then convinces Jennifer.

Likewise, the other three pairs all come to agreement from the first set of cases that the deep structure matters. They all end up writing similar rules based on the first set of cases. However, when it comes to the second set of cases, the high transfer pairs sustain focus by *honing in* on this deep structure. For example, the high transfer outcome pair sees the second set of cases and immediately confirms their former rule.

> **Jennifer:** She looks at the new set of red cases. **“**So I would like to keep it?”
>
> **Marc: “**Yeah.” They both start writing their rule and discussing the task directions with a researcher. “What do you think it is? Right now it looks almost the same. More weight towards the back. Hmm… It feels pretty much the same.”

Here Jennifer is the one to quickly confirm that the rule from the first set of cases applies again. She has determined the importance of the deep structure from the first set of cases, and then hones in on that structure when she sees the new cases. Marc confirms aloud that the deep structure is greater mass back. Similarly the other high transfer pair considers the importance of height and putting weight in the middle for the first set of cases, before focusing on the deep structure. Yet when they see the second set of cases, they immediately *hone in* on the deep structure to confirm their rule. In this way, honing in on the deep structure helps both high transfer pairs sustain their focus on it.

In contrast, both low transfer pairs do not hone in on the deep structure, which interrupts their concentration on the deep structure. Even though both low transfer pairs write about the deep structure when looking at the first set of cases, they loose focus on it when they see the new cases. For example, when the low transfer learning goal pair sees the second set of cases, they start by noticing a whole bunch of features, some of which are irrelevant. They end up focusing on irrelevant features that only occur in a few cases, and ultimately fail to come up with a rule that involves the deep structure.

Similarly, the low transfer outcome goal pair does not hone in on their rule from reflection one that contains the deep structure. Instead, they spend the second reflection discussing many features, some of which are irrelevant. However, when they notice a feature, they do work together compare cases in order to evaluate if that feature is significant. The dialogue below shows an example of how this cross-case comparison helps this pair dispel the idea that center of mass is dictated by how much weight is above the balance point.

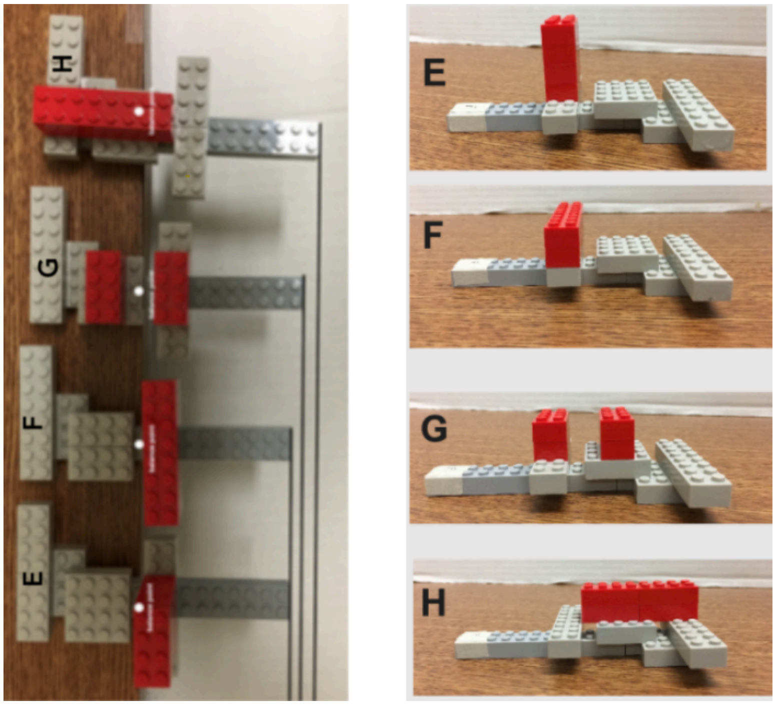

Figure 15. Second set of red cases, presented to students during reflection 2. Each student had a color photo of these top and side views of the cases, as well as physical versions of these cases, which were shown in the classroom.

Excerpt from Low Transfer Pair:

Raven: "The red parts are what represent the center of mass I think."

Padma: **“**Not necessarily for each one. Look at G.” She points to case G. [*contrasting cases*]

Raven: **“**Yeah I know. But maybe it has two different center of masses, to help it balance more. Unless there can only be one.”

Padma: **“**Like, I'm saying, they...”

Raven: **“**I'm trying to say center, is like a point. One point.”

Padma: **“**Like look. The difference might be that, the way that the red pieces are *spread out*.” [*highlighting deep feature: distance*] She points to the red part of case E.

Raven: **“**Yeah... the way the red pieces are distributed.” Both write on their sheet. Raven looks back at the red cases. “What do you notice about the structures that stick out the most?”

Padma: **“**What did you notice about the structure that sticks out the most? That now the ***stacking*** rule didn't really work. Like you see how the…” [*highlighting irrelevant feature: height*] She points to case E. “See how structure E stacked all of theirs right on the balance point? It didn't work.”

Raven: **“**What?”

Padma: **“**You see look.” She points to the top view of case E on her sheet. “You know how the last one…” She takes out the yellow cases. [*comparing cases*] “That stacking?” *She points to the tower in case A.* [*demonstrating deep feature: height*] “It never works.” She points to case C. [*comparing cases*] “See every time they stack, it doesn't work. It only works for this one.” [*demonstrating* and *clarifying deep feature: height*] She points to the top view of case C. “But still.”

Raven: **“**It only worked for this one because this,” she points to the tower in the top view of case C, “is to the top” points to the very back of the base of case C “of the balance point I think.” She points to the balance point of case C.

Padma: **“**Yeah...and it's near the balance point.” She points to the balance point of case E top view. [*comparing cases* and *clarifying*] “The stacking was near the balance point. So, it ‘doesn't really work’. Ya feel?” [She makes air quotes with her fingers when she says “doesn’t really work”]

Raven: **“**Mhm. So...”

> **Padma: "**Or, I could write... what is it? The ones, that are more like. I can write the same thing that I wrote on that one. The ones that are more…" She circles all the bases the red cases. "…focused on their ***weight beyond***, ***after their balance point***, have…***stick out more***." [*contrasting cases* to *highlight* the *deep structure*] She points to case H and makes a gesture with her pencil, motioning in the direction of further onto the table. [*clarifying* and *demonstrating deep structure*]
>
> **Raven:** Raven looks at the yellow cases. **"**Yeah. I want to say that like the ones with the red, that have at least some red on the top...work more". [*contrasting cases*] She rubs the image of the yellow Legos on case D.
>
> **Padma: "**Uh-huh."

The dialogue above shows how the pair ultimately does notice the deep structure, but it takes a while for them to get there. Raven's initial idea is that the part of the cantilever with the most weight represents the center of mass, which can be one or many points. Padma dispels this idea by *contrasting* cases and pointing out that the label for center of mass is not above where the red weight is on each cantilever, so that can't be the rule. Padma then *compares* cases to determine that the height of the Legos does not affect the balance point. After dispelling these misconceptions, they go back to confirm their rule from the first set of cases and draw their attention back to the deep structure of the problem: greater mass back.

So even though both high and low transfer pairs notice the deep structure during the contrasting case reflections, only high transfer pairs were able to focus on that deep structure throughout both contrasting case reflections. This focus came from the ability of the high transfer pairs to hone in on the deep structure after the first reflection, which in turn helped them sustain their concentration on that deep structure when looking at the second set of cases. The low transfer pairs did not hone in on the deep structure, which in turn hurt their focus during the second set of cases. Instead they used the second set of cases to notice irrelevant features.

Although the low transfer pairs were ultimately able to re-notice the deep structure, their concentration on the deep structure was interrupted throughout the task. These interruptions and lack of focus on the deep structure may have hurt their later transfer ability.

Referencing resources to identify features and structures. The third way that high transfer pairs focused on the deep structure was by using resources more effectively.

First, high transfer pairs referenced resources more often. While the low transfer pairs tended to only reference the center of mass reading and contrasting cases images at the beginning of the build period, the high transfer pairs referenced them throughout, especially when they hit an impasse in their building process (Figure 16).

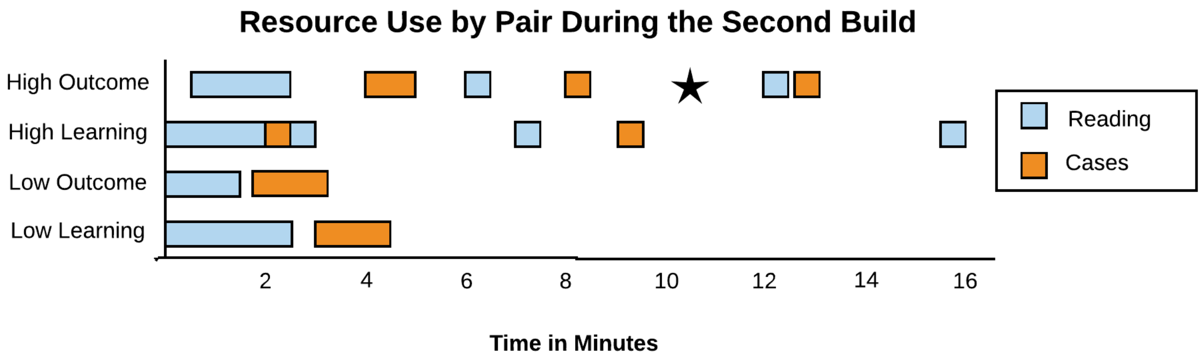

Figure 16. Graph of referencing behavior over the course of the second build period. Every 30-second interval of the build period was coded as to whether or not a resource was being used. The star marks when the high transfer outcome goal pair completed the engineering design challenge and therefore stopped building.

Furthermore, when using the resources, high transfer pairs noticed features to implement and test in their designs. For example, the high transfer learning goal pair references the reading initially to confirm that the deep structure is correct and important. However, when they try to implement that idea into their cantilever, it's not successful. At this impasse, they reference the reading again to see what else they can try.

Excerpt from High Transfer Pair:

Samantha: "That's the part that's annoying." She sighs. "Okay but…we can make it. I have to like, move the balance point."

Lindsay: Looks at the reading. [*referencing*] "Maybe if I make this smaller," she points to the back of the cantilever, "because in…"

Samantha: "That part?" She points to the back of the cantilever.

Lindsay: "Yeah. 'Cause look." Lindsay picks up the reading and points to it.

Samantha: "Yeah so I have to make this thing ***weigh more***." She points to back of cantilever. [*highlighting deep structure*] "Like that one." She points to image of broom on the reading (Figure 17). [*referencing deep structure*]

Lindsay: "Like wider." [*referencing irrelevant feature*]

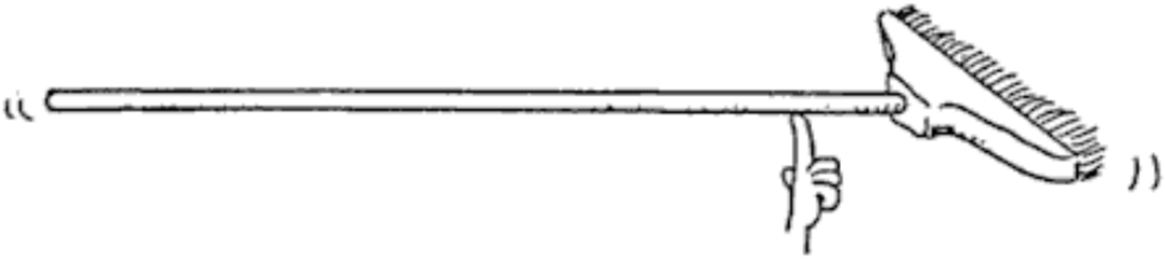

Figure 17. Image of broom found in the center of mass reading resource.

In this segment, the pair gets an idea from the reading—make the cantilever wider to increase the amount of weight on the table. Although this is a misconception, it does provide an idea to the students, which they can then test. It is interesting to note that the girls don't then go and try to build a broom. They aren't noticing the broom's general shape, with all its component parts. Instead, they notice the feature of width. In response, they build a cantilever where just a couple of Lego pieces stick out horizontally (Figure 18). In this way, the students incorporate the feature of width into their cantilever, instead of copying the structure whole cloth.

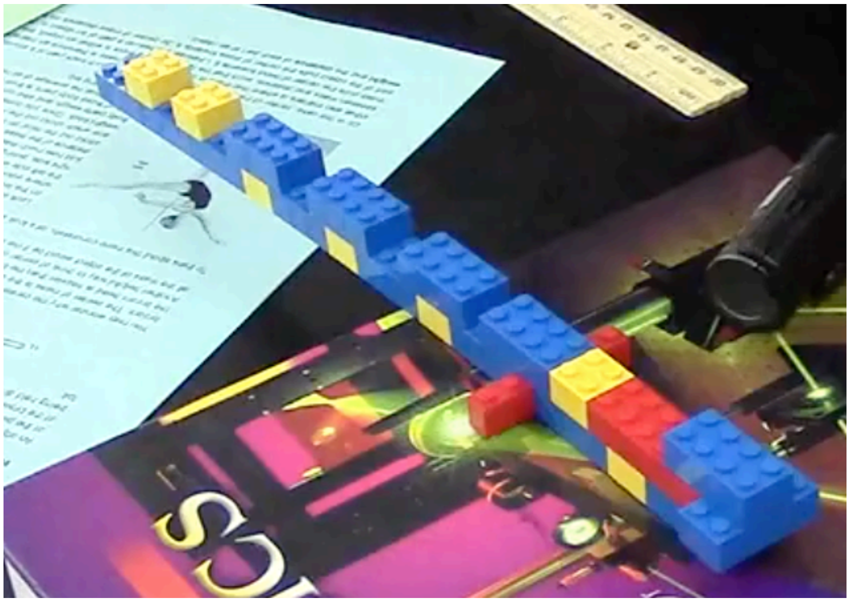

Figure 18. Samantha and Lindsay's cantilever after they discuss making the base wider like the broom in the center of mass reading.

A similar thing happens in the other high transfer outcome pair when they are using the cases. They hit an impasse, and look at an image of the contrasting cases. Then they realize that the cases have spaces in them, which increase the distance.

Excerpt from High Transfer Pair:

Marc: "How could I make?

Jennifer: "I'm just scared to touch it at all. You know what I mean?" She takes apart the back and tries to pull it back together so that it's more flat.

Marc: "Yeah it breaks apart so easily. Wait! ***Something I see in here*** is that they leave some empty ***spaces*** here you see?" *He points to the base of cantilever C on the cases sheet*. "In between." [*highlighting deep feature: distance*]

Jennifer: "Yeah. I can try that." She takes apart base of their cantilever again.

Marc: "Let me see. Do you get what I mean?" Jennifer makes a flat back with spaces between the Legos. [*demonstrating deep feature*] "Yeah like that! Do you think that helps?"

Jennifer: "We'll see." She keeps building out the base of the cantilever.

Marc: "Because they leave like some kind of empty space to make it longer with wasting that much..." He watches Jennifer build.

Here Marc is again thinking about a single feature (spaces between Legos) to borrow from the cases and incorporate into their cantilever. Like the other high transfer pair, Marc and Jennifer don't try to re-create the case itself. They simply take a feature (space) and incorporate that feature into their own design. By adding space between Legos, they are increasing the distance between each weight. At the end of the build period when the pair makes a cantilever that does stick 10.5" off the table Marc tries to evaluate why they were successful. He looks at their final cantilever and says, "So it looks like I had to do is somehow make more space in between, like to make it longer." He is *highlighting* that increasing the distance was important. So the high transfer pairs used the cases to get ideas of features to incorporate into their designs.

This is different from the approach that the low transfer pairs take. Instead of looking at features to integrate into their designs, the low transfer pairs copy whole segments of a case. For example, the low transfer outcome pair only looks at the contrasting cases once during build 2, when Padma tries to build out a segment of one of the yellow cases.

Excerpt from Low Transfer Pair:

Padma: Padma is looking at the two sets of contrasting cases. She starts by taking a line of blue and yellow Legos and moving some of the pieces around.

Raven: "OK, wait, wait, wait. Hold on." She takes the cantilever away from Padma. "Are you trying to like ***copy*** what they did?" [*referencing to copy cantilever whole cloth*] Raven starts trying to take the cantilever apart. "Just trying to..."

Padma: "So like make like, you know like this." She takes the cantilever back from Raven. "Like they did, but don't."

Raven: **“**What do you mean?”

Padma: **“**Like*, maybe I should stick to their idea*. Copy it, but not copy it. Get it?”

Padma is unable to name the specific features of the case that she is trying to copy. Instead, she just wants to copy the case as a whole. She never ends up saying what about the case she expects will make their cantilever successful. After attempting to build one section of one of the yellow cases (Figure 19), and realizing that it didn’t stick far off the table, Padma abandons the cantilever and the students build something that looks completely different. They don’t reference the cases, or center of mass reading for the rest of the build. Furthermore, during the whole build period they never discuss the reading in relation to the cantilever they are making.

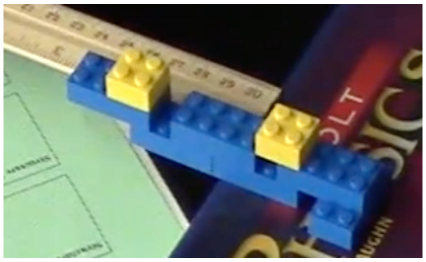

Figure 19. Padma’s cantilever.

Similarly, the other low transfer pair tries to build a whole section of one of the red cases.

Excerpt from Low Transfer Pair:

Alonso: **“**I wonder how they did that?” He points to something on the red case sheet. [*referencing*] “Like, try to take this out, and how did they have all of this, exactly? Ok, for example, these aren't connected, or are they?”. He points to the red cases.

Rebecca: **“**They are, by like this little piece.”

Alonso: **“**Oh, they are. I see. Ohhhh! That's why. So let's take this.” He puts a yellow Lego on some blue Legos to connect them.

Rebecca: **“**See those little blue on top...”

> **Alonso: “**Right there...”
>
> **Rebecca: “**OH!”
>
> **Alonso: “**Because....”
>
> **Rebecca: “**I think *they're using one of these*.” She picks up a blue Lego. [*referencing to copy the shape of the case*]
>
> **Alonso: “**Yeah, because we're trying to do that whole thing,” he points to the base of case G, “and then...”
>
> **Rebecca: “**Are you using this?” Rebecca builds something wide out of the Legos. Alonoso builds a line. **“**I think I did this.” Rebecca points to the back of case F.

The language of this pair as they try to copy, indicates that they are not highlighting any distinct features from the cases. Unlike the high transfer pairs who highlighted features of distance and width, this pair never names a feature. Instead, they attend to the concrete details of which types of Lego go where, while trying to copy the case whole cloth.

In this way, both low transfer pairs fail to reference the resources to notice features. Since low transfer pairs discuss the cases in very concrete terms (e.g. “Maybe I should stick to their idea. Copy it.” or “I think they're using one of these…I think I did this”) they fail to highlight the features of the cases that make them successful. In contrast, the high transfer pairs are able to articulate how conceptual ideas from the resources work in relation to their own designs (“We have to make this thing weigh more” or “They leave like some kind of empty space to make it longer”). I should note that the low transfer pairs don’t completely ignore deep features when referencing the resources. For example, the low transfer learning goal pair does look at the center of mass reading at the beginning of their build period, and notice the deep structure. They then spend a large part of the build period (unsuccessfully) trying to add more weight to the back of their cantilever. So even though low transfer pairs do notice the deep structure in the resources, and subsequently try to incorporate it into their build, this type of behavior happens a lot more in high transfer pairs.

Therefore, even though all four pairs referenced the resources, high transfer pairs referenced them more often. Furthermore, while low transfer pairs typically copied examples whole cloth from the resources, high transfer pairs typically identified single features to incorporate into their cantilevers.

Systematic testing to uncover relevant deep features and structures. Once they had identified specific features from the resources, high transfer pairs then tested the impact of those features on their cantilevers. This systematic testing in turn helped high transfer pairs focus on the deep structure.

One reason why high transfer pairs may have been more effective is because they tested their structures more often than low transfer pairs (Figure 20). As a result, high transfer pairs were able to evaluate the significance of individual features on their designs. In this way, high transfer pairs were able to rule out irrelevant features more effectively, which helped them focus on the deep structure more. In contrast, low transfer pairs measured their cantilevers rarely, and only after having made many changes to their designs. In this way, low transfer pairs were not able to identify if individual features of their cantilever were relevant or not. This made it hard for low transfer pairs to develop a focus on the deep structure.

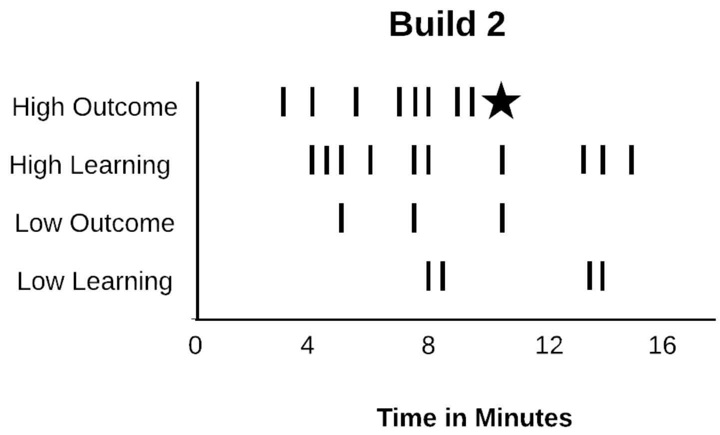

Figure 20. Graph of student testing over the course of the second build period. The star marks when pair 1 completed the engineering design challenge and therefore stopped building.

For example, the high transfer outcome goal pair had a disagreement during the second build period about what features were important. Jennifer thought the cantilever needed greater weight in the middle but Marc thought that weight should be back. They took a measurement and then systematically tested Jennifer's idea of putting weight in the middle.

Excerpt from High Transfer Pair:

Marc: He is measuring the cantilever. "It's like ten and a quarter." [*testing*]

Jennifer: **"**Maybe...2 more lines." She points to the markings on the ruler to indicate that they are two sixteenths of an inch from their goal.

Marc: **"**Could I try putting this in the back for one turn?" He takes a blue block that is in the middle of the cantilever and moves it to the very back of the cantilever. [*changing a single feature: weight middle to weight back*]

Jennifer: **"**Go ahead. We've been doing the same thing again and again."

Marc: **"**Pretty much."

Jennifer: **"**Yeah. That's why I was trying to get it here." She points to the middle of their cantilever.

Marc: "In the middle, the thing is in here we're just putting more weight in the middle." He motions to the middle of the cantilever. "I don't know what we're doing man."

Jennifer: "That's why." She pushes down on the middle of the cantilever. "To stabilize it." Marc moves some blue blocks from the middle of the cantilever to the back.

The cantilever breaks while Marc is measuring it, but when he gets to measure it, he sees that the cantilever sticks 10.5" off of the table, and they hit their goal. In this way, he was able to demonstrate to Jennifer that by taking weight from the middle and moving it back, the cantilever was able to stick out farther. By testing, he is able to clarify that having greater mass in the middle is irrelevant. As a result, at the end of the build period, Jennifer writes on her notes sheet "make more weight on the back." This evidence suggests that Marc convinced Jennifer that placing the weight farther back helped balance the cantilever more effectively. In this way, systematic testing helped dispel Jennifer of the misconception that placing mass in the middle of the cantilever was important, and he instead got her to focus on the deep structure.

Similarly in the high transfer learning goal pair, Lindsay wanted to put the weight in the middle of their cantilever, but Samantha wanted to put the weight back. Near the end of the second build, they are making small adjustments to their cantilever, measuring after each change.

Excerpt from High Transfer Pair:

Samantha: Samantha takes a block off the ***middle*** of the cantilever. "I feel like if I put that here…" She ***moves the block to very back*** of the cantilever. [*testing weight middle versus weight back*] She then pushes the cantilever farther off the book until it falls.

Lindsay: "Got it." She helps Samantha put the cantilever back on the book. Samantha re-adjusts the cantilever until it's just about to fall.

Lindsay: "Is it there?" She measures how far off the book the cantilever is. [*testing weight middle versus weight back*] "It's still eight."

> **Samantha: "*It was better.*** Let me..." [*confirming weight back is better than weight middle*] She takes another block off the middle of the cantilever and puts it on the back of the cantilever.

Although there is not a large (i.e. at least a half inch) change in their cantilever after moving just one block, Samantha recognizes that when she takes blocks from the middle of the cantilever and moves them back, the cantilever is able to stick out a little bit longer. Instead of moving all the weight from the middle of the cantilever to the back and then testing it, she instead systematically does it, measuring the difference after moving just one block. This type of fine grain testing is rare, even for this pair, which tests their cantilever more than any other pair. However, even when moving several Legos before testing again, this pair usually only changed one feature of the cantilever at a time. For example, right after this scene, Samantha takes the weight in the back that is in a tower, and without moving it forward or back she lays that same weight out horizontally, before testing again. This might imply that she was testing to see if the feature "width" is relevant or not by testing weather changing the width of the structure while keeping the weight at the same distance affected the center of mass. By ruling out the irrelevant features, this pair is able to focus on the significance of the deep structure.

Contrast this scene with the testing behavior of the low transfer dyads. Instead of testing systematically to determine which features are deep and which are irrelevant, the low transfer pairs test rarely, and only after making large changes. This makes it difficult for them to accurately determine which features cause differences in the center of mass of their cantilever. For example, the low transfer outcome goal pair makes four cantilevers that all look completely different. They only test three times during the second build—once after each new construction (they run out of time before even testing their fourth cantilever). As a result, they can't tell what features of their different structures are successful or not. There are too many variables at play.

Similarly, the low transfer learning goal pair only measures two versions of their cantilever. They measure each version twice. So although they test four times in total, they only really test two different cantilevers. By the end of the build period, they know the types of changes that they have made, and they know that their second cantilever is longer, but they can't identify which feature lead to that improvement.

Excerpt from Low Transfer Pair:

Alonso: "We made a two inch increase." [*Testing*]

Rebecca: "True, wait, uh, point five." They both write on their notes sheet. **"**Oh I should... oh wait, I think I got this confused." She erases her note.

Alonso: "Our second one was..."

Rebecca: "Wait." She reads her sheet.

Alonso: "Our second one was where I got six, right?"

Rebecca: "Six was, yeah, six."

Alonso: "In the second rule, which was ***added more***..." He motions to the ***front part*** of their current cantilever. [*attributing test results to weight in front*]

Rebecca: "We used ***a bunch of yellow Legos***," she points to the front of the cantilever, "***on this side" she points to the back of the cantilever***. [*attributing test results to weight back*]

Alonso: "That was, yes, that's why, because..." he motions to the back of the cantilever. "Mkay." He goes back to taking notes.

Rebecca: "And then I had an extra red one."

Here there is some disagreement from the pair about what lead to the extra length. Alonso seems to believe that the cantilever stuck off more because of what they added to the front of the cantilever. In addition to the dialogue above, Alonso wrote on his notes sheet, "it was 7", use more Legos for hanging." On the other hand, Rebecca thinks it stuck off more because of what they added to the back. So even though they tested their cantilever to measure how successful it was, the pair disagrees about what caused that success. As a result, the students end the task thinking about different features, with no clear evidence about what features are important for the task.

This disjointed understanding again shows that low transfer pairs lack focus on the deep structure of the problem. Across both low transfer pairs we see how erratic testing behaviors were unable to help students focus on what was important. In contrast, the high transfer pairs use systematic testing to determine which features are irrelevant, and ultimately validate the importance of the deep structure.

Discussion

This comparative case study shows that focus on the deep structure is a major distinguishing factor between high transfer pairs and low transfer pairs. By establishing a joint understanding of the deep structure during the first build, and sustaining concentration on that deep structure throughout their analysis of the contrasting cases, high transfer pairs developed an early focus on the deep structure. During the second build, strategic use of resources to identify features, and systematic testing of those features, helped high transfer pairs determine the importance of that deep structure. Together, these focusing mechanisms enabled high transfer pairs to establish a prolonged, joint focus on the deep structure and its importance throughout the task, in a way that low transfer pairs didn't.

These findings are not particularly unexpected, since many of these behaviors have been studied before. For example, this study's discussion of developing a joint understanding of the deep structure is in conversation with work by Clark (1996), who has discussed the importance of language in helping students achieve "common ground" to develop shared knowledge when working jointly on an activity. Furthermore, work by Chi (2009), has studied the significance student pairs co-constructing knowledge during joint-dialogue for learning and transfer. However, I take a novel perspective on these works, by considering how students establish joint understanding of a problem's deep structure. I use a noticing frame to illustrate that demonstration and clarification may be key ways for students to develop this joint understanding. Furthermore, I argue that literature on co-construction of knowledge for transfer should consider what students are attending to. Specifically, this literature should consider if students are focusing on deep structure, and how this focus may affect students' transfer ability.

This case study work also contributes to the literature on resource use. Although a lot of work has been done on how resource use affects learning (e.g. Aleven, Stahl, Schworm, Fischer, & Wallace, 2003; Gräsel, Fischer, & Mandl, 2000; Land & Greene, 2000; Nicol, Littlejohn, & Grierson, 2005), I suggest that resources can direct students to focus on the deep structure of a problem. In this work, high transfer pairs used provided resources to identify new features to test. This eventually helped them focus more on the deep structure. In contrast, low transfer pairs only used the resources to copy designs whole cloth. This direct copying may have hurt their transfer ability. These findings are in line with work that has shown that students are less successful when they just copy examples to guide their designs instead of using scientific principles to guide their design (Worsley & Blikstein, 2015).

Findings also showed that high transfer pairs tested what they found in resources systematically, while low transfer pairs tested rarely. This finding supports work that has been done on control of variable strategy (CVS), which suggests that the use of CVS is imperative for scientific theory building, even though the skill can be difficult to teach and transfer (e.g. Chen & Klahr, 1999; Kuhn, Schauble, & García-Mila, 1992). However, I take a novel approach to this literature by viewing it with a focusing framework. Specifically, this case study considers how CVS enables students to focus more on the deep structure of the problem at hand. By systematically testing one variable at a time, students are actually changing their focus from irrelevant to more relevant features of the task. This suggests that the CVS literature can be broadened to consider how CVS affects focusing on deep structure for transfer.

Together, this work has implications for how hands-on engineering design tasks can help students focus on deep structure in order to support transfer. First, this case study suggests that students dialogue and building processes can affect transfer. Findings suggest that students should be encouraged to use materials and resources more often, especially when they hit an impasse in their work. Furthermore, this case study suggests that resources should be used to help students identify features to test. These teaching techniques are already used in some successful engineering design curricula, such as Learning by Design (LBD; Kolodner et al., 2003). LBD encourages students to pull out “rules of thumb” that they think are important for the task. Students are then encouraged to test these rules of thumb, and update them if tests suggest that they do not make designs more successful. Other work has shown that when students test their ideas early and often they have more successful designs and transfer more effectively (e.g. Marks, 2017). However, this case study suggests that such tests should also be focused on testing singular features, so that students can determine which features of their cantilever are relevant and irrelevant for the success of their design. It also expands theoretically on this work by suggesting that these design processes may aid transfer by means of helping students better focus on the deep structure of the problem.

Next, this case study both supports and broadens the literature on bridging and transfer. Theoretical work has argued that trying to actively connect content between contexts aids transfer (Salomon & Perkins, 1989). Therefore, its not surprising that students who tried to find the deep structure across multiple contexts, were better able to apply that deep structure to new problems later. However, this comparative case study adds to Salomon and Perkins' theoretical work by supporting it with empirical evidence. I found that only high transfer pairs attempted to apply their rule from the first set of cases to the second set of cases, suggesting that actively attempting to connect between contexts in this way may have helped them transfer more effectively later. This finding implies that when students practice transfer in the learning context, they may be better able to transfer that same knowledge out of the learning context to solve novel problems later. This is not a very surprising finding, but it does have implications for how to support transfer from engineering design tasks. Specifically, it suggests that engineering design tasks should involve "bridging activities" that scaffold students to both notice and apply the deep structure in multiple contexts. These bridging tasks may help students focus on the deep structure, and practice transferring. This may in turn aid transfer out of the task, and into new problems.

Ultimately, this work suggests that simply helping students notice the deep structure of a problem may not be sufficient for transfer. This is important because most of the transfer and perception literature only talks about noticing (e.g. Greeno et al., 1993; Lobato et al., 2012, Schwartz et al., 2011), not focusing. However, I found that all students noticed the deep structure during both build periods and both cases reflections. It was only the ability to focus on that structure that distinguished high transfer pairs from low transfer pairs. Therefore, I suggest that future work on perception and transfer look more closely about how students are focusing on the deep structure over time. This focus on deep structure may be especially important for students trying to learn and transfer from complex, hands-on tasks, where many other features compete for their attention.

Limitations

Although this case study provides a rich illustration of how focusing on deep structure may affect transfer, it is unable to identify a causal link between these constructs. Future work should empirically test the effects of these focusing mechanisms on transfer.

Another limitation of this study is that the high transfer pairs may have focused so much on the deep structure of the problem, that their focus actually lead them to not process the second set of contrasting cases very deeply. The second set of cases were designed to highlight common misconceptions such as height or width, but the high transfer pairs just concentrated on the deep structure and failed to dispel these misconceptions. In contrast, the low transfer pairs did deeply process the second set of cases, and thus used them to confront some misconceptions. As a result, the high transfer pairs' strong focus on the deep structure might have hurt their ability to learn from the second set of cases. Consequently this lack of focus may have benefit the low transfer pairs. It is important to acknowledge that although strong focus on the deep structure was prevalent in the high transfer pair, it may have also hurt a learning process that could have helped their transfer ability. There is an opportunity for future work to assess the tradeoffs of these two processes.

Conclusion

This comparative case study investigates how students come to develop a focus on the deep structure of an engineering design problem in order to transfer core science concepts to novel problems. The study takes a focusing lens when looking at how behaviors involving building, resource use, and partner dialogue affect transfer. While both high and low transfer pairs noticed the deep structure of the task, only high transfer pairs were able to establish a joint understanding of the deep structure, sustain concentration on it when evaluating cases, and subsequently use resources and testing, to determine its importance. These behaviors also helped students rule out the significance of other features that they noticed during the task. As a result, high transfer pairs were better able to focus on the deep structure over the course of the task.

From this work, I bring a novel theoretical perspective to the perceptual learning and transfer literatures. While lots of work has implied the importance of noticing deep structure for transfer (see Chapter 2 of this dissertation), I propose that simply noticing, may not be enough. In addition to noticing, behaviors that focus students on the deep structure of the task over time may be key to ensuring students' ability to value the significance of the deep structure. This value may in turn be what leads students to be more successful on new problems in new contexts.

CHAPTER 4: CONCLUSION

Together, the chapters of this work signify that learning goals, contrasting cases, and focus on deep structure may be key mechanisms for student learning and transfer. These findings have several implications for how to support learning and transfer, especially through supporting students' noticing and focusing processes, construction processes, and use of resources.

First, the two papers above discuss the importance of both noticing and focusing on deep structure. The quantitative analysis in Chapter 2 suggests that having students notice the deep structure of a problem may be a key component to transfer. This corroborates work that has theorized (Greeno, Moore, & Smith, 1993) and empirically found (e.g. Schwartz et al., 2011) a link between deep structure noticing and transfer. However, the case study analysis identifies that noticing may only be one stage of transfer. After noticing deep structure, it is important that students know how to engage with these concepts meaningfully over time. For example, consider Perkins and Salomon's (2012) theory of how students transfer. They propose that students must first detect the deep structure (essentially noticing it), then elect to use that information in the transfer context, before finally trying to connect the deep structure to the affordances of the transfer context. I propose that an additional step should be added to this process, whereby students choose to engage with these concepts over time, even when other information could be detected, elected to be used, or attempted to be connected. In this way, the transfer literature has failed to acknowledge the importance of engaging with deep structures over time, or identifying the significance of deep structures in relation to other information a student might use to solve a problem. It might seem like the quantitative and qualitative study findings are at odds, because the quantitative study shows a link between just noticing and transfer, as the literature would suggest, while the qualitative study shows that focusing is more important than just noticing. However these findings are not necessarily mutually exclusive. For example, it could be that in the larger data set of the quantitative study, noticing was significantly related to transfer, but since the study failed to measure focusing, it failed to account for the effects of focusing on transfer. Likewise, the small sample of the case study may make it seem like noticing doesn't matter, while focusing on deep structure does. However, this might not be the case across a larger population of students. The fine grain data of the case study also allowed for us to measure noticing in a more nuanced way than the quantitative analysis, which could have made it seem like low transfer students notice a lot less than they actually do. Finally, the case study does not necessarily prove that noticing doesn't matter; it simply shows evidence that focusing is another, separate process that should also be considered when thinking about how students perceive and reason about deep structures. This relationship between noticing and focusing should be explored in future work.

This relationship between noticing and focusing also has implications for teachers, educational technology and curriculum designers, and practitioners. It can be easy for teachers to just see if students recognize the core principles of the task,. However, simply noticing the deep structure, while an important part of the transfer process may not be sufficient to support optimal student transfer. Instead, attention should also be paid to how students understand the importance of the deep structure over time, even when other ideas are competing for students' attention. This may mean assessing students differently to make sure they can recognize the significance of the deep structure across many different task contexts, especially after they are presented with other information that could inform their work.

This dissertation also provides ways to support students' ability to focus on deep structure. Activities that help students develop a joint understanding of the deep structure could help students focus. Additionally, students might be encouraged to focus on the deep structure when presented with other ideas, to use resources to find other ideas to test, and to use evidence based testing to validate the significance of the deep structure of the task. When it comes to building process, the quantitative study showed that better constructions were associated with higher transfer test scores, while the case study showed that building and testing systematically may help students focus on the deep features and structures of the task. In this way, the two studies taken together may indicate that students who were able to iterate on their structures in a more thoughtful way both built better structures and focused on core principles that helped them transfer. This has implications for engineering design tasks, since these findings indicate that the building process itself may promote students to think deeply and ultimately transfer.

However, these findings can also be applied outside of engineering design tasks. For example, in a social studies classroom, a teacher may provide contrasting cases to aid deep structure noticing by asking students to identify a single theme that is present across several historical events. The teacher could then help students focus on that theme by using discourse to help the students in the class develop a common understanding of that concept. Students could engage in "building" like processes by trying to map the deep structure (historical theme) to various events throughout history, and could "test" to see how well that concept can be used to explain these events better than other concepts or themes. Of course, these are just a few ways that focusing on deep structure might be supported. Future work should consider other mechanisms or means of supporting student focusing on deep structure.

Another takeaway from this set of studies is that learning goals and contrasting cases may be means of supporting transfer during learning. In the quantitative study these two manipulations improved students ability to transfer, and the qualitative study showed how students who worked with contrasting cases effectively were able to address misconceptions and focus on the deep structure of the task. Although work has shown that contrasting cases can be used to support learning and transfer (Alfieri, Nokes-Malach, & Schunn, 2013; Schwartz et al., 2011; Bransford & Schwartz, 1999) little work has considered the significance of learning goals in supporting contrasting cases activities. Although the case study analysis was not able to discern how learning goals supported students' transfer ability, this again could have been due to the limited sample of the case study. Since the quantitative paper failed to identify which variables mediated the effect between learning goals and transfer, it was difficult to discern from the actions of just four pairs students what other factors could have caused learning goals to aid transfer in the presence of contrasting cases. Future work should explore the mechanisms of this interaction in greater detail.

The interaction between learning goals and contrasting cases is an interesting finding for practitioners however, because learning goals and contrasting cases are fairly easy interventions that teachers and practitioners can add to learning activities to help students transfer more effectively from these activities. This is especially important for hands on activities like engineering design tasks, which typically focus students on developing a desired outcome instead of learning core science content.

However, future work may explore the non-dichotomous nature of learning goals and outcome goals. After all, students should ideally be able to think deeply about science concepts in relation to their designs *and* design effectively engineered products. In other fields, like the achievement goals literature, there has been work exploring what happens when mastery and performance goals are combined (e.g. Linnenbrink, 2005; Senko, Hulleman, & Harackiewicz, 2011). Similarly, some work has explored the tensions that exist when students try to take on both engineering and science goals during an engineering design activity (Leonard, 2006). Findings from this study confirm that engineering goals focus students on performing well on the task, and science goals that focus students on understanding the conceptual content of the activity are often at odds as students ignore science content to tinker their way to a solution. Yet there are ways to reconcile these two important objectives. One way to meet these two goals might be focusing students on modeling the scientific principles of the task in order to understand the underlying science principles of it (Hamilton, E., Lesh, R., Lester, F., & Brilleslyper, M. 2008; Leonard, 2006). However, further work should explore how learning goals and outcome goals may interact to help students effectively learn and transfer science concepts, while designing successfully. This might involve a more nuanced analysis of how students transfer science concepts into their builds during the design process, and how those processes can be more effectively supported.

Again these principles can still be applied outside of the engineering literature. For example, in an English classroom, teachers may give students learning goals that focus students on understanding keep writing principles and skills instead of outcome goals that focus students on writing a good essay on any single assignment.

Finally, these two studies address the benefits of using resources to support student learning and transfer. The quantitative paper showed that learning goals improved how much students perceived resources to be valuable, which in turn was associate with higher learning. The case study identified how using resources more often and “smarter” could help students notice features and structures to test. This in turn was associated with better transfer. So in addition to corroborating work in the significance of resources for learning (e.g. Aleven, Stahl, Schworm, Fischer, & Wallace, 2003; Gräsel, Fischer, & Mandl, 2000; Land & Greene, 2000; Nicol, Littlejohn, & Grierson, 2005) these two findings show how resources may affect learning and transfer, Valuing resources may help students learn from them, while using them wisely may help students focus on the deep structure of the task. Again, these novel findings would need to be investigated through further research before we can understand exactly how student engagement with resources affects learning and transfer.

As educators move to creating rich activities that give students agency to explore, it is even more essential that scholars provide ways to help effectively scaffold students during these activities. Furthermore, it is important to understand not only how students learn material but also how to support students’ ability to transfer knowledge across broad, varied contexts. Although transfer can be incredibly difficult to achieve, there are some ways that it can be supported. This work suggests that learning goals, contrasting cases, and focus on deep structure may be three means of scaffolding learning and transfer processes. Although these factors still need further study, this work provides some perspective on how these interventions may be beneficial for students, especially when engaged in complex, ill structured problems.

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APPENDIX A: QUANTITATIVE MOTIVATION ANALYSES

The following analyses were cut because they were determined to be outside the theoretical scope of either journal paper. They are presented here as auxiliary results for consideration.

Self-Efficacy Results

Across both studies, self-efficacy was measured immediately after students were given, their goal, and then again after the engineering design task.

Study 1

Measurement. Self-efficacy was measured using a six-item survey given on a 7-point Likert scale. Some items were adapted from the Physics Learning Self-Efficacy Instrument (Lin, Liang, & Tsai, 2015). It was designed to be a local measure of self-efficacy, which was specific to the engineering design activity that students were given. The survey asked questions like "How confident are you that you can explain how to solve this task using physics principles?" or "How confident are you that you can apply what you learn about physics from this task to a new problem?" Students were asked to rate how confident they were on each of these questions on a scale of one (not at all confident) to seven (very confident) with 4 indicating a neutral level of confidence (somewhat confident). Reliability for this scale was high both at pre ($\alpha = .874$) and at post ($\alpha = .926$). Final pretest and posttest scale scores were determined by averaging student ratings across all six items.

Results. Students who were given a learning goal ended the engineering design task with higher self-efficacy. A two-way repeated measures ANOVA with task goal as a between-subjects factor and time (pre vs. post) as a within-subjects factor showed an interaction between task goal and time $F(1,84) = 4.14$, $p = .045$, $\eta_p^2 = .05$. Post hoc test revealed that there was a significant difference between task goal conditions at post $F(1,84) = 4.824$, $p = .031$, $\eta_p^2 = .05$, but not at pre, $p = .515$. Specifically, students assigned a learning task goal finished the task with higher self-efficacy than students who were assigned an outcome task goal (Figure 21).

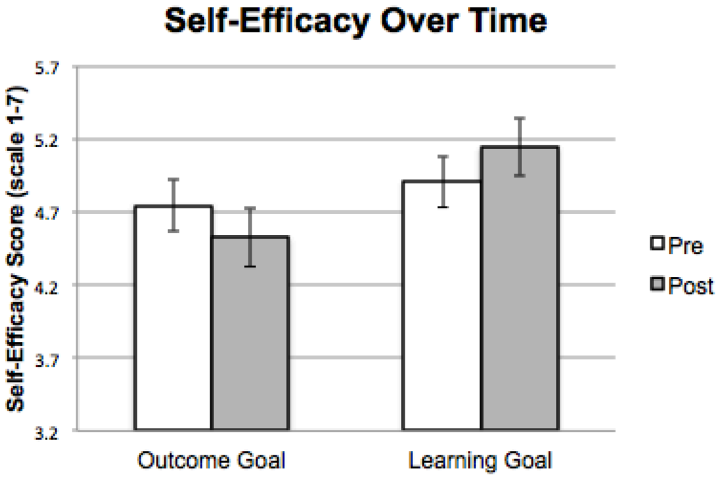


Figure 21. Study 1 estimated marginal means (+/- 1 SE) of student self-efficacy scores at pre and post.

Study 2

Measure. Since the school site for study 2 had much shorter class periods, measures had to be shortened in order for students to finish the study in one school week, without cutting down on instruction or engineering design activity time. For this reason, one question from the self efficacy scale that correlated the worst with the other scale items, was removed. Even with the shorter 5-item scale, reliability on this measure was high at pre ($\alpha = .922$) and post ($\alpha = .833$).

Results. Students who were given a learning goal did not the engineering design task with higher self-efficacy than students who were given a task goal. A two-way repeated measures ANOVA with task goal as a between-subjects factor and time (pre vs. post) as a within-subjects factor showed no significant interaction between task goal and time, $p = .49$.

Statistically, students who were given a learning goal did not finish the task with higher self-efficacy than students who were given an outcome goal (Figure 22).

Figure 22. Study 2 Estimated marginal means (+/- 1 SE) of student self-efficacy scores at pre and post.

APPENDIX B: STUDY MATERIALS

Reflection Questions

Contrasting Cases Condition

Reflection 1 questions. There is one **rule** that defines where a structure's balance point is. Compare and contrast the example structures in front of you. What is the same between these structures? What is different between these structures? What do you notice about the structures that stick out the most? What do you notice about the structures that stick out the least? Now write your best description of the **rule** that defines where a structure's balance point is. Make sure your rule explains why some structures stick out more than others. ***If you're not sure what a rule is, here is an example rule for determining the speed of an object:*** *An object's speed is determined by both distance and time such that the more distance something travels in a given amount of time the faster the object's speed.*

Reflection 2 questions. To help you with today's engineering design activity, you should reflect. There is one **rule** that defines where a structure's center of mass is. Compare and contrast the example structures in front of you. What is the same between these structures? What is different between these structures? What do you notice about the structures that stick out the most? What do you notice about the structures that stick out the least? Now think about your **rule** from reflection 1. Based on what you notice here, would you like to keep or update your rule? If you want to update it, what would you change?

No Cases Condition

Reflection 1 questions. To help you with today's challenge, you should first reflect. The video you just watched gave an introduction to working with Legos. Reflect on some challenges that may come up as you work with Legos. What is difficult about working with Legos? What is easy about working with Legos? What excites you most about this challenge? What difficulties might you come across during this challenge? Now think about other times when you have worked with Legos. ***Give an example of what you built and how you felt about the experience. If you don't know what to write here is an example:*** *When I was a kid I used to build full size castles with Legos. It was a lot of fun to play in them but I found it hard to come up with new ideas of what to build, so I usually just copied my brother.*

Reflection 2 questions. To help you with today's challenge, you should first reflect. The building activity you just may help you with the next activity. What is difficult about this building task? What is easy about this building task? What makes this an engineering design activity? What would you change about this activity? Give an example of something you did during the build task that made you feel like an engineer. ***If you're not sure what an example of acting like an engineer is, here is an example of one engineering principle:*** *When I was building I made something that was strong and that would hold up without breaking. Engineers build structures that are high quality through their work.*

Task Goals

In addition to getting a list of materials and a in image illustrating what a balance point (proxy term for center of mass) is (Figure 23), students were given a unique set of instructions based on their goal condition. Note that all students had access to their notes sheet for reference throughout the entire engineering design task.

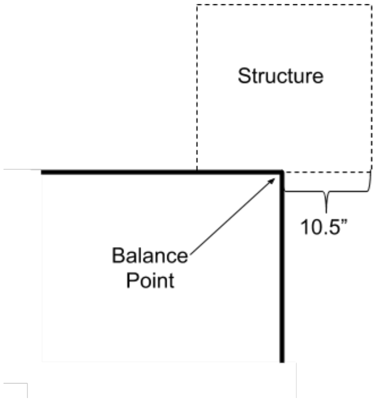


Figure 23. Image of what a “balance point is” on the students’ goal sheet.

Outcome Goal

Objective: Build a structure that doesn’t fall or break.

Task: Today’s challenge is to build a structure that sticks 10.5” off the table, using the materials listed below. The structure must be free standing, meaning that it cannot touch anything other than the **top of the table**.

Why? Building structures that balance is an important engineering skill. Engineers know how to make structures that don’t fall or break.

Test: Once you have built your structure, you can test it by pushing it off the table until it is about to fall. Then measure how far off of the table the structure can hang. You have completed the challenge when your structure can hang 10.5” off the table without falling, breaking, or touching anything other than the top of the table.

Learning Goal

Learning Objective: Develop an understanding of how objects balance.

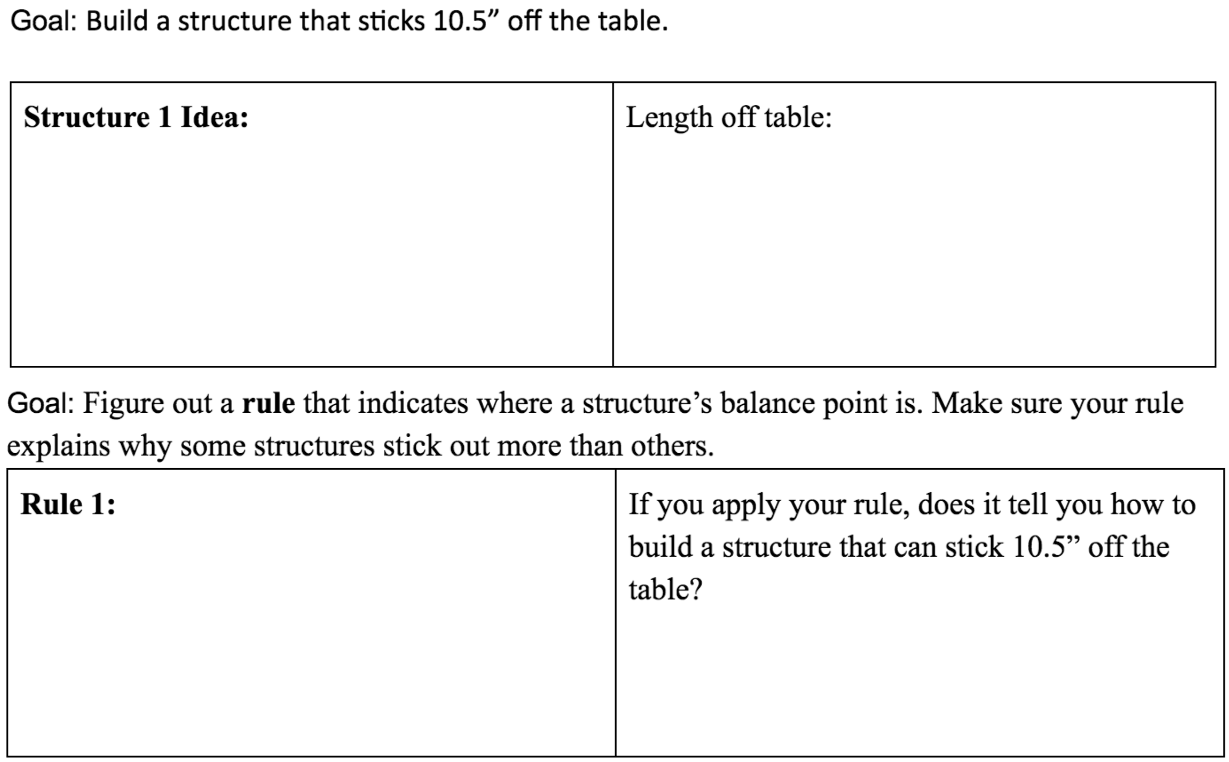
Task: Figure out a **rule** that indicates where a structure's balance point is. Make sure your rule explains why some structures stick out more than others.

Why? To be able to build structures that balance, I must first know where the balance point is in the structure. When you understand how changes to the structure move the balance point, then you will know how to build a structure that can balance without falling or breaking.

Test: Once you have made your rule, you can test it by building a structure with a balance point that is 10.5" back from the front of the structure. If your rule is correct, this structure will be able to hang 10.5" off the table without falling, breaking, or touching anything other than the top of the table.

Notes Sheet Prompts (Study 2)

In study 2, students in both conditions were given a notes sheet for each build period. On this sheet, they could write down five ideas that could lead them to accomplishing their assigned goal. Next to each idea, they could write down an evaluation of how close that idea got them to their goal.



Goal: Build a structure that sticks 10.5” off the table.

Structure 1 Idea:	Length off table:

Goal: Figure out a **rule** that indicates where a structure’s balance point is. Make sure your rule explains why some structures stick out more than others.

Rule 1:	If you apply your rule, does it tell you how to build a structure that can stick 10.5” off the table?

Figure 24. Note sheet prompts for the Outcome goal condition (top) and Learning goal condition (bottom).