Discourse Analysis of Middle School Students' Explanations during a Final Design Review (Fundamental)

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Abstract

Recent reform efforts in K-12 education, in the United States and globally, have necessitated further research on design learning among K-12 students. One of the key competencies necessary for design and solving problems is the ability to fluently transition between concrete aspects of a problem (such as artifacts and problem context) and abstract concepts such as scientific and mathematical principles. While such fluency is difficult even for adult learners, contemporary studies show that young children can transition between abstract and concrete ideas and can effectively make trade-off decisions. The purpose of this study is to understand how students make these connections as they defend their trade-off decisions and final design solutions during a design review session. Using discourse analysis methods, we analyzed interviews between nine middle school students and two external judges that occurred during a final design review session. We used the Legitimation Code Theory to study semantic gravity (their trade-offs decisions are highly depending on the context or students empirical reasoning) and semantic density (transitions between specific design criterion and multiple trade-offs) in student explanations. This study confirms the importance of eliciting student ideas with targeted questions and helping students make fluent transitions between concrete aspects of a solution and abstract concepts while balancing design trade-offs. We argue that such dialogue is necessary for students to develop a deep understanding of disciplinary core concepts and successful design solutions.

Keywords: Semantic waves, engineering design, trade-offs, decision-making, middle school

Introduction

One of the most prevailing research questions in engineering education is related to how students learn to design and how they apply their understanding of scientific and mathematical principles as they develop design solutions. While most of the research in design is conducted with professionals and undergraduate students, recent reform efforts in K-12 education, especially in the United States, have necessitated further research on design learning among younger students [1].

The importance of engineering design in K-12 education has increased in recent years due in part with its integration in the Next Generation Science Standards [1], [2]. The iterative nature of the engineering design process allows students to explore the problem context, develop solutions, and evaluate their solutions [3]. However, the engineering design process is complex and engages complex cognitive processes associated with critical, analytical, and creative thinking [4]. Moreover, the unique relationship between the artifact developed and the context in which the artifact will function (Kroes, 2002; Simon, 1981) adds to the complexity of the process.

The design process necessitates not only the understanding the design problem but also the application of scientific and mathematics knowledge to the developed solutions. Hence, engineering design requires students to be able to transition between concrete and abstract ideas while understanding the problem, balancing trade-offs and making decisions. As students design, they also learn to fluently transition between concrete aspects of a problem such as design artifacts and problem context and abstract concepts such as scientific and mathematical principles. In addition, design problems necessitate balancing competing criteria in association with the technical, economic, and social aspects of a solution.

While such fluency is difficult even for adult learners, contemporary studies show that young children can have the abilities to transition between abstract and concrete ideas can effectively make trade-off decisions [5]. However, few studies had focused on understanding the connections between these transitions in the design process, and how they can be elicited.

Purpose

The purpose of this study is to examine the application of the Legitimation Code Theory to explaining how students communicate their design decisions as they defend their decision solutions. More specifically, we aim to understand how students make concrete and abstract transitions in their final design reviews while recognizing multidisciplinary aspects of the design challenge. We focus our study on discourse that occurred during design review sessions. Teacher questioning, if used effectively, can promote effective classroom dialogue and student learning [6]–[8]. By eliciting student thinking, questioning invites elaborations and necessitates answers with several sentences as opposed to brief phrases [6]. Hence, questioning can uncover deeper understandings that are not readily available and reveal student misconceptions. In this qualitative and exploratory study, we examined the extent to which design review conservations elicit such complex thinking and depth in student reasoning.

Theoretical Framework

In this study, we used the legitimation code theory and more specifically semantic gravity and semantic density, to explore abstract knowledge across specifications in the design problem, and the relational levels among different concepts or ideas. The Legitimation Code theory (LCT) has been used to support knowledge-building by enabling dialogue between theory and data or to relate theory and practice [6]. Used in many disciplines such as biology, physics, nursing, English, cultural studies, music, and design, LCT connotes five principles that explain disciplinary dispositions, practices, and discourse: a) autonomy; b) density; c) specialization; d) semantics; and e) temporality. Each one of these principles has a variety of modalities, known as Legitimation Code. For this study, we explored students' transitions from concrete to abstract through the principles of density and semantics. For this study, we focused on context-dependent epistemic relationship, known as *Semantic Gravity* (SG), and the condensation of meaning within socio-cultural practices, known as *Semantic Density* (SD). Semantic gravity captures different types of knowledge and the essence of the context-dependence of meaning. In Semantic Density, condensation refers to the addition of multiple meanings to a symbol or terms [7] or compounding of a meaning [8][9] [10], while Semantic Gravity can be represented by connections between terms or concepts. Semantic gravity and density can be strong (+) or weak (-). However, more variations are possible depending on the empirical outcomes of each study.

Adaptation of the Legitimation Code Theory to our Study.

A seminal study that used the legitimation code theory in engineering design was conducted by Wolmarans [11], [12]. Wolmarans adopted the earlier legitimation code models to inferential reasoning in design. We then further built on Wolmarans' model and represented the relationships between semantic density and gravity as an intersecting direct and inverse relationship (See Figure 1). Different modality waves are also possible in different quadrants of our model. This model helps us visualize where a student shifts between abstract theory and practical application and between disciplinary and multidisciplinary reasoning.

The rights side of our model, labeled as design, represents the modality that Wolmarans suggests as being most important in design. This modality of high context-dependency and interdisciplinarity, is represented on the right side of Figure 1, and coded as (SD++/SG++). In our study SD+/SG+ indicates that the student balanced trade-offs through multidisciplinary connections and made the connection from abstract to concrete to develop a solution. In comparison, First Principles (SD--/SG--), represents theoretical abstraction associated with deep disciplinary knowledge.

When a student translates a theoretical, abstracted knowledge into a useful application, he or she enters into high gravity(SG+). To cross into the high density quadrant, SD+, a student must demonstrate ability to apply concepts in rich descriptions and with multi-disciplinary implications. When a student balances design trade-offs and communicates a connection between an abstract concepts and a concrete representation, we can claim that this student has achieved strong modalities in Semantic Gravity (SG) and Semantic Density (SD).

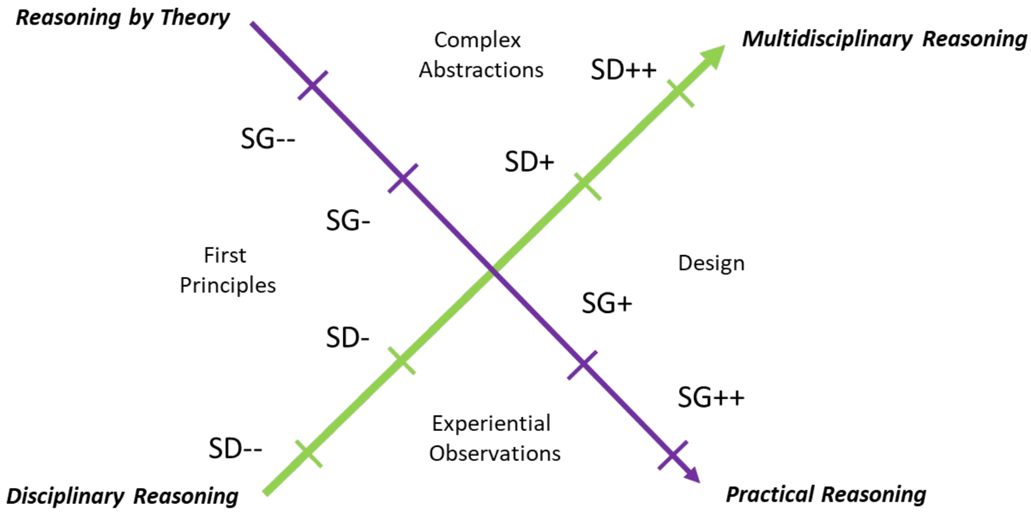

Figure 1. Adaptation of Wolmarans' model [11] *to our study.*

Methods

Research Participants and Data sources

This study was conducted at a middle school in the United States. Nine students from seventh grade, and two external reviewers participated in our study. During the final design review of an energy efficient house students were interviewed by external reviewers who aimed to understand students' design decisions and final designs. The interview questions were not pre-determined but the interviews typically started by one of the interviewers commenting on a design feature and asking the students to elaborate on the decisions students has made. From the perspective of the external reviewers, the aim of these interviews was to understand students' design decisions before selecting the best designs among the group.

Data Analysis

Using discourse analysis methods, we analyzed transcripts of interviews recorded between the middle school students and the external reviewers. We used a discourse analysis method to analyze the transcripts using the coding model illustrated in Figure 1 and further explained in Table 1 and Table 2. We examined semantic waves in students' explanations, as well as the design reviewers' questions.

Table 1. *Coding Protocol for Semantic Density (Disciplinary-Multidisciplinary)*

Code	Definition	Example
SD++	Student integrates multidisciplinary concepts in their explanations that are coherent with their trade-offs, but at the same time with higher complexity	"When my net energy reached -200 KWH, I started to focus on reducing cost. I could have made my windows smaller but I wanted to have plenty of light entering the house. I identified windows and walls with higher U-values, which is not good for energy but cost less." (example quote)
SD+	The student has a sequence in their explanations considering the implications from different disciplines in his/her trade-off decisions	"… the larger the surface area in summer it could consequently make the roof very hot which can basically increase AC usage which is probably something that will…Because in my first test that was actually one of the first issues the AC skyrocketed when up like the nineties and in December drop." (Student TH3_7)
SD-	The student has a sequential explanation that can be across different disciplines. However, there is no evidence she/he considered concepts from other disciplines during their trade-off decisions.	"Well I change the roof a lot because it was, the way it works, at first, I had the roof panels on the wrong side of the house, and then I had to move them that around a bit. I also tried to make it (the roof) flatter and other roof designs to see the way the sun reflected more." (Student PS1_7)
SD--	Student explains he/her decisions by facts and there is no connection between disciplines.	"So basically, when I started making my house, I started with a rectangle box basically, and I kept adding to it. It was obviously houses aren't rectangular…" (Student TS4_7)

Table 2. *Coding Protocol for Semantic Gravity (Theory-Practical)*

Code	Definition	Example
SG--	Reasoning is based on theory and remains in abstracted and idealized form.	"Heat transfer is the movement of thermal energy from one object to another one with lower temperature"
SG-	Reasoning is led by theoretical considerations, but reasoning is still abstract although situated in material realities.	"So, in the winter…it is this tree, it might not affect as much, but I guess the branches might give some shadow with the leaves." (Student RT5_7)
SG+	Reasoning is led by practical consideration such as empirical tests but informed by theory.	"(trees) Yes, if I put it on the north on the south, they did not make that much of a difference, when it put on the east to west, they really impacted my energy." (Student TS4_7)
SG++	Reasoning is based on practical considerations devoid of links to theory.	"…Yes, I also changed like the windows and the roof to mess around with the cost and try to see what affected the cost." (Student PS1_)
0	There is not enough discourse to be able to classify it in any of the semantic code.	"They are on this side right here." (Student DL6_7)

The first round of our analysis was to record semantics used by students and reviewers. This allowed us to identify the types of terms and phrases used and furthermore categorize them. The first round of coding focused only on semantic density and the integration of multiple disciplines in students' trade-off decisions. The second round of coding focused on semantic gravity. When necessary, the code was re-defined through discussions among the researchers.

Results

We visually illustrated each interview session in terms of their progression across questions and answers. As illustrated in Figure 1, question one, the design reviewer asked the student, Pete, to describe his early house design versions he has created.

Interviewer 1 (Question 1)	You talk about realistic and that you needed to minimize costs and you needed to maximize your efficiency. What were some of your earlier versions of this house like?
Pete	Oh my early version, there is like a lot of like… kilowatt hours were like, much higher and I don't have many windows and like there aren't as many details because I have to articulate later on to make it more beneficial.

Pete's explanations mapped to low semantic density (SD--) as the descriptions did not connect to multiple disciplines. Instead, Pete describes them as a sequence of 'facts' explored in the practice. As a result, the semantic gravity is higher because the student relies more on the empirical evidence. This case was typical for many students. However, few of them managed to defend their design decisions with conceptual abstractions. For Pete, the design reviewer question that helped to connect abstract concepts to concrete was related to the data used for making design decisions.

Interviewer 1 (Question 6)	One final question for me, and it sounds like you collected a lot of data with the house. What was some of the most important data analysis that you did?
Pete	I think I was just trying to make sure that your house was efficient but also kind of like worked with the cost making sure that was actually realistic and not like too far-fetched or not possible.

As illustrates in Figure 2, Pete's explanations were concentrated heavily on Experiential observations with one connection to Design thinking.

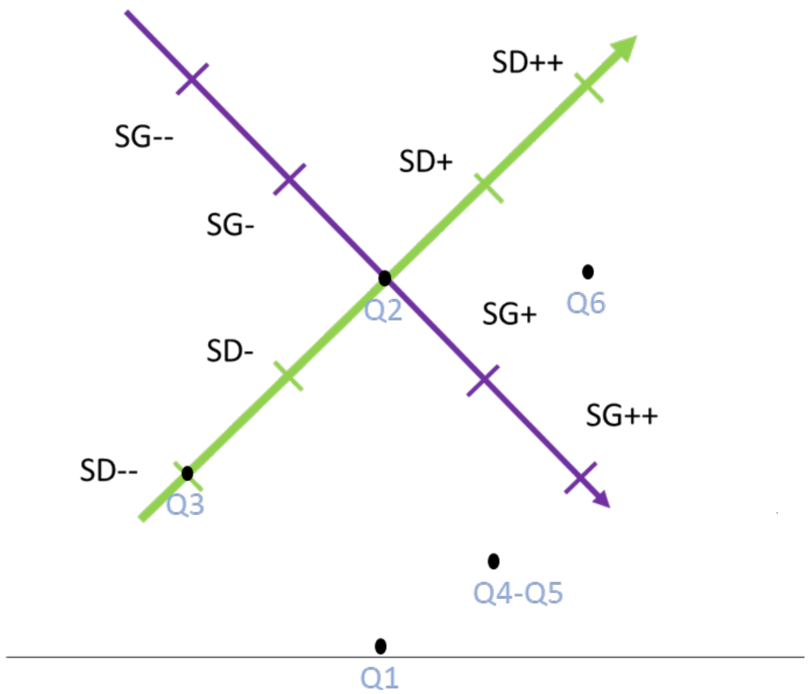

Figure 2. The Semantic Density and Gravity Profile of Pete

Similar to Pete, Teri's explanation to the first question was represented with high gravity as shown in Figure 2. This was the case for many students.

Interviewer 1	I get a really nice design of the house as we were looking at. Can you tell me a little bit about what your steps were in making this house energy efficient?
Teri	Well I change the roof a lot because it was, the way it works, at first, I had the roof panels on the wrong side of the house, and then I had to move them that around a bit. I also tried to make it (the roof) flatter and other roof designs to see the way the sun reflected more.

The questions by the reviewer allowed Teri to further elaborate on her design decisions. Throughout the interview, the semantic spread increased, reaching to three different quadrants.

Interviewer 2 (Question 7)	And I noticed that you have one tree can you tell us how you decided where to put the tree, and what are the benefits and disadvantages of having a tree?
Teri	Well the tree, well I just put it where gets [indistinct] with the rest of the house, but some of the advantages of that in summer it cools the house down like having the shade of it, but in the winter it can actually make the house cooler, so that could be an disadvantages of it because you have to use the heat more.

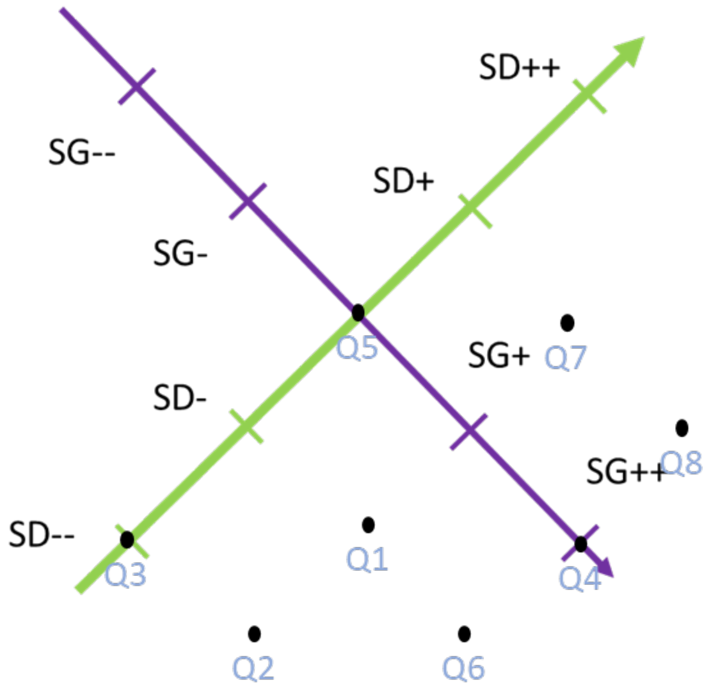

Figure 3. The Semantic Density and Gravity Profile of Teri

As illustrates in Figure 3, Teri's explanations were concentrated in two quadrants: Experiential observations and Design thinking. Compared to Pete, Teri's explanations are more fluent in its reach to different dimensions of semantic density and gravity.

In our analyses, the waves of semantics that started with the first interview questions and evolve through questions suggest that the connection that students made from concrete to abstract and from disciplinary to multi-disciplinary views were elicited by reviewers' questioning. Even though, this inquiry was not effective in all cases, most of the time, these questions on data, decisions, disadvantages and benefits of trade-off decisions, elicited denser and deeper explanations. While the reviewers' questions were eliciting higher gravity modes at the beginning of each design review, the questions evolved over time to elicit abstractions and multidisciplinary justifications.

Discussion

Our study illustrates an application of the Legitimation Code Theory used to explain how students communicate their design decisions during a design review session. In this paper, we presented evidence of questioning by the design reviewers to uncover middle students' trade-off decisions and how students attempted to connect concrete (the designed object) and abstract ideas (disciplinary core ideas). Evidence of semantic gravity was strong in early stages of the interview, meaning students focused their explanations on concrete design ideas. However, students' explanations often became clearer with the elicitation of the reviewers with questioning. This study confirms the importance of eliciting student ideas with targeted questions and helping students make fluent transitions between concrete design features and abstract disciplinary core concepts as well as fluent multidisciplinary understandings necessary for balancing trade-offs.

The implications of this study to classrooms is significant because teacher questioning play an important role in shaping classroom discourse. Our findings inform strategies for teaching and learning through teacher or peer questioning. Teachers' questions are a common component of classroom talk, and hence play an important role in determining the nature of discourse during instruction. The kinds of questions that teachers ask and the way teachers ask these questions can influence the type of cognitive processes that students engage [13]. We suggest that classroom discourse aims to connect concrete ideas to abstract disciplinary core ideas while expanding students' understanding of a problem from multiple perspectives and an awareness of trade-offs.

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