Effects of Technology-based Support for Explanation Construction on Learners' Discourse during Design-based Learning in Science

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Abstract: We examine the effects of a software-based approach to scaffolding explanation construction on learners' discussion in a design-based learning environment. The approach consists of having learners collaboratively work around a software-based explanation-construction tool in the context of addressing their design needs during design investigations. We conducted a study where three sets of participants completed a one-week hovercraft unit with the same teacher. We have analyzed the data collected from two sets of participants where one set was facilitated by only the teacher in their explanation efforts and the other set was facilitated by both the teacher and our software called SHADE. Results indicate that participants who used the software engaged in higher quality explanatory discourse by the end of the unit. This research supports the usefulness of a contextualized explanation-construction tool in promoting explanatory discourse.

Introduction

Approaches to enculturating learners into the epistemic practice of explanation construction continue to receive significant attention in educational research because of the recognition that articulating and applying explanations is closely tied to advancing one's conceptual understanding (Coleman, 1998; Sandoval & Reiser, 2004; Vattam & Kolodner, 2006). Our research has investigated the promotion of explanation construction among middle school students learning science in a design-based inquiry environment. We have found that learners' development and their ability to participate effectively in such a practice are heavily dependent on teacher expertise in scaffolding that practice and modeling the discourse of explaining (Ryan & Kolodner 2004). Having noticed that not all teachers have this kind of expertise, we have been seeking technology-based approaches to complement teacher facilitation to help middle-school learners become better scientific explainers (Vattam & Kolodner, 2006). In this paper we will present one example of this approach, a software tool called SHADE (Science of Hovercraft Aided by Designing and Explanation). SHADE's explanation-construction component is connected to a design exploration and investigation component. The explanation-construction tool illustrates and frames, through an external representation, the essential elements of a causal explanation of an observed physical phenomenon.

Our purpose in this study is to investigate the potential of such an explanation-construction tool to overcome some teachers' lack of strong content knowledge and explanation-construction capabilities. Can such a tool, integrated into a design-based learning environment in ways that allow learners to recognize its usefulness, help enculturate learners into becoming better scientific explainers? More specifically, we examine the affordances of SHADE as a collaborative explanation-construction tool for enhancing explanatory discourse and explanation construction in the classroom. Our overall research hypothesis is that (a) by contextualizing explanation in design needs of learners, we can encourage them to want to explain, (b) by contextualizing explanation in design exploration and investigation, learners will get direct experience at explaining their observations, and (c) by employing a representational framework that models explanatory discourse, learners will be scaffolded into generating more conceptually and structurally elaborate explanations during whole-class discussions and presentations.

Background

Learning to formulate explanations is an important aspect of the scientific enterprise (Coleman, 1998). Recent theoretical work supports the view that it is essential to participate in the discourse practices of disciplinary communities to gain a deeper understanding of discipline-specific concepts (Lave & Wenger, 1991; Roth, 2001). Therefore, many inquiry-based learning methods, which seek to place the learners in the role of scientists, face the prospect of dealing with enculturation of their learners into the epistemic practice of scientific explanation.

Although explanation-based interactions affect individual achievement in the context of group learning, research shows that learners will not naturally generate efficient explanations on their own and need support to do so (see studies cited by Coleman, 1998). In our design-based approach to science learning, called Learning by Design (LBD) (Kolodner et al., 2003), teachers enculturate learners into scientific explanation through exposure, experience, and discourse modeling. As learners progress through the LBD unit, learners not only engage in design engineering, but also conduct experiments and collect data from these experiments to inform their future design choices. In the context of presenting their experimental procedure, data and conclusions, the teacher attempts to facilitate explanatory discussion by helping learners focus their comments on explaining their findings in terms of causal mechanisms. In this way, learners are helped with socially constructing scientific arguments.

But our research has also shown that some teachers are not as successful in facilitating scientific explanation as others, especially those who are not as fluent with the science content, as skilled at modeling the discourse of scientific argumentation, or as able at focusing learner discourse on the underlying science concepts (Ryan & Kolodner, 2004).

We have adopted a technology-based approach to complement teacher facilitation in helping middle-school students become better scientific explainers. Our first attempt involved the integration of a software tool called SIMCARS into an LBD unit, *Vehicles in Motion*. SIMCARS included an explanation-construction tool that was designed to be used by learners working in pairs or small groups around a computer in the context of conducting experiments and collecting data. The explanation-construction tool consisted of an explanation template that served as an external discursive representation. A discursive representation (Sandoval et al., 2003) is one that represents elements of a scientific explanation as opposed to, say, simulations which represent a physical phenomenon on a computer. Integration of SIMCARS influenced the *Vehicles* unit in a two ways. First, by situating learners' explanation construction in the activity of experimentation and data collection, it situated their explanation and scientific argumentation in their design needs and in the design space. Second, it distributed the responsibility of scaffolding learners' explanation construction across the teacher and the tool. Learners' inclination to scientifically explain their design investigation findings without expert facilitation suggests that a tool like SIMCARS holds potential to bridge the design-science gap among learners and help at least some individuals develop a better understanding of the content in a less teacher-dependent fashion (Vattam & Kolodner, 2006).

Discursive representations have been a subject of much study in the context of scientific knowledge construction (Bell & Linn, 2000; Sandoval et al., 2003; Scardamalia & Bereiter, 1994; Toth et al., 2002; Vattam & Kolodner, 2006). A majority of those studies, including our earlier SIMCARS research, have focused on individual achievement in the context of group learning. Only some of them have examined the role of such representations as mediational resources (Roschelle & Teaslay, 1995) facilitating collaborative interactions. Suthers & Hundhausen (2002) reported the effect of such representations on learner discourse in the context of within-group collaboration. In this paper, we present a new analysis that explores the influence of discursive representation on learner discourse in the context of inter-group collaboration.

Study

Figure 1: Model hovercrafts from design challenges

Shade: Software design

SHADE software was designed in the context of an LBD-style unit called *Hovering around Tech* (henceforth referred to as "the *Hovercraft* unit"). This unit was developed to teach physics concepts related to working hovercrafts and practices of designers and scientists, all in the context of learners designing and building model hovercrafts and carrying out investigations needed for successful design. The unit was designed such that over the course of a week-long science summer camp (approximately 26 hours), the learners, working in small groups, addressed four successive design challenges that increased in complexity with respect to both functionality and science concepts involved: a balloon hovercraft, a flying saucer hovercraft, a 2-fan hovercraft, and a 1-fan hovercraft (see figure 1 for typical models of each kind).

SHADE was developed to promote specific "explanation-construction" interactions in the classroom culture. Our previous research with SIMCARS suggests that such interactions need to be situated within the context of learners' design needs and design investigations to bridge the design-science gap (Vattam & Kolodner, 2006). Furthermore, the more designs learners explore, the more opportunities there are for such interactions to take place. However, opportunities for exploration in the real world are limited due to time and material constraints. Therefore, there is a need to augment the real-world design environment with a virtual design environment that imitates the real world but in a way that both expands the design space for the learners and also allows for more efficient exploration of the space. Therefore, SHADE incorporates a simulation-based virtual design environment in which learners can explore variations of the four hovercraft designs mentioned above.

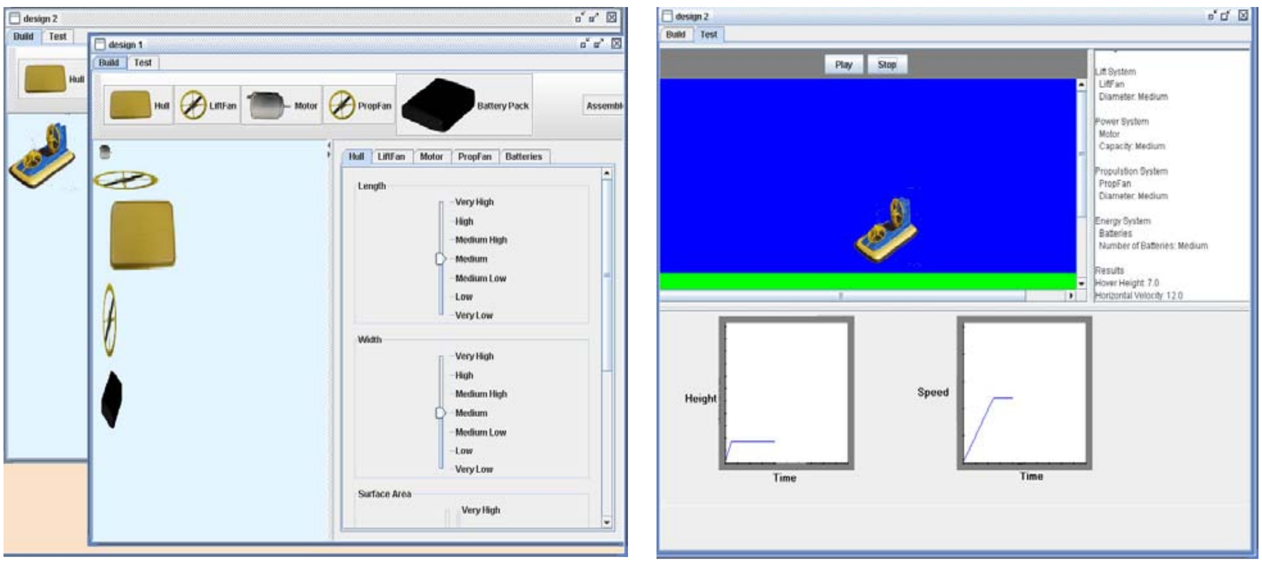

Figure 2: (a) Design area. (b) Test area

To maximize design exploration and to maximize the potential such exploration has for promoting explanation construction, each of the four design challenges was structured in such a way that half the time our learners would be designing and testing real hovercraft models and half the time they would be experimenting with simulated models in the virtual design environment. For instance, in the initial phases of each challenge, they would "mess about" (Kolodner et al., 2003) with real parts and build real hovercrafts. Later, during the design-driven investigation phase, when they are investigating issues important to designing a better-working hovercraft, work would shift to the virtual design environment where they could quickly design new craft and collect consistent data across designs. Finally, when the time came for designing their best hovercraft, they would use what they had learned through the software to design and build a functioning hovercraft that they could race with other groups' crafts.

To facilitate this back and forth movement across real and virtual models, and to help learners transfer knowledge gathered in one medium to the other, we recognized that there had to be correspondence between the real and virtual design environments in terms of how the devices look and behave. The virtual design environment of SHADE has a design area and a test area. Figure 2 (a) shows the design area in SHADE where one can see the correspondence between virtual crafts and the real models depicted in Figure 1. In the design area, users can quickly configure a hovercraft to match their conceptual design by clicking on the various parts and adjusting their parametric values. Figure 2 (b) shows the test area. Learners can test their design in the test area, which animates the behavior of the design along with a graph that plots the hover height versus the hover time. They can also pause and step through the simulation.

An important aspect of design-based investigation is the comparison of many design variations to determine the factors that account for the differences in their behavior. To facilitate this process, SHADE includes a design comparison feature that allows learners to compare multiple designs side-by-side as shown in Figure 3 (a). After choosing the designs for comparison, they have the option of predicting the outcome of running those designs side-by-side, generalizing the prediction as a rule of thumb, and explaining the science behind the predicted outcome. For instance, let us assume that learners were comparing 3 designs (D1, D2 and D3) similar in every respect except that the weight of D3 was greater than the weight of D2, which in turn was greater than the weight of D1. Based on discussions already had in class, learners might predict that "Design 3 will have the lowest hover height." After running the investigation to see if indeed that was true, they could extract a general rule of thumb, "to maximize the hover height, keep the hovercraft weight as low as possible." But the prediction and the rule of thumb alone will not account for the underlying science that would explain them. At this stage, there is an option for learners to launch the explanation-construction tool to back up their prediction or justify their rule of thumb. Figure 3(b) shows the prediction and the rule of thumb that a learner entered and the corresponding explanation entered by the same learner in the explanation-construction tool.

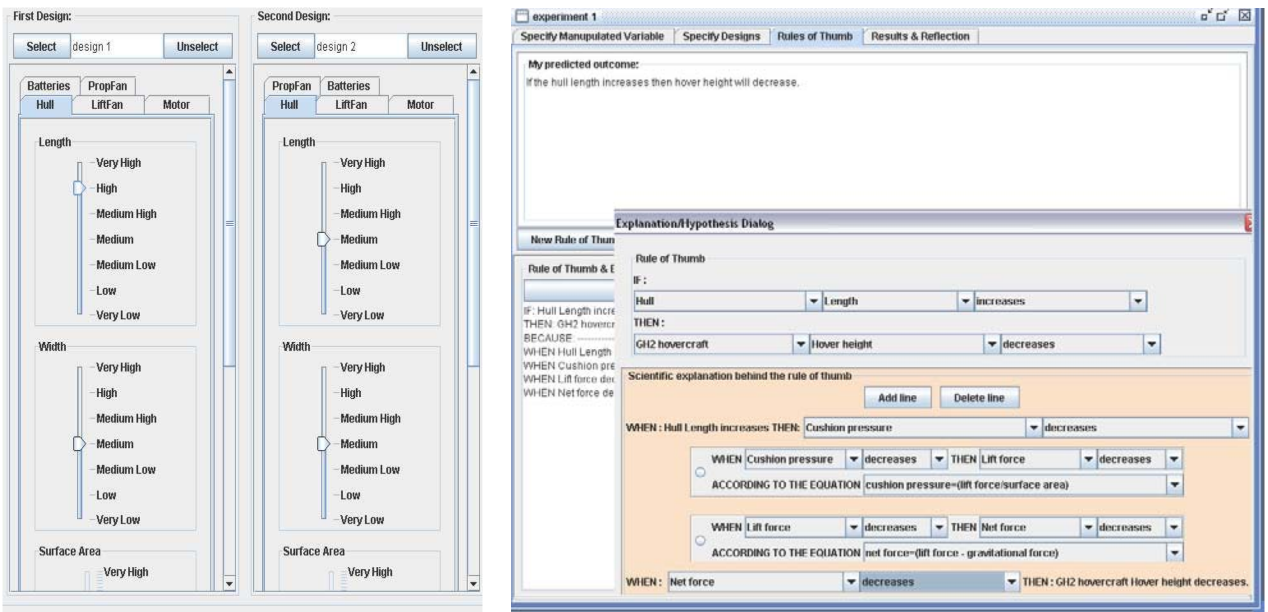

Figure 3: (a) Design comparison. (b) Explanation-construction tool

The Hovercraft unit design and integration of the software

The hovercraft unit was developed to teach physics concepts related to working hovercrafts and the practices of designers and scientists, all in the context of designing and building small hovercraft. The one-week unit was broken down into four design challenges followed by a final presentation to an external audience at the end. For each design challenge, the following sequence of activities takes place:

- **Messing about:** A playful exploratory activity where learners construct a modestly-working device of the kind they will be redesigning later and tinker with it to discover its capabilities and ways of making it better.
- **Whiteboarding:** As a whole class, groups share their experiences and ideas for achieving the challenge and articulate what they need to learn more about. They also discuss what they think they know, and the teacher might present some science content related to what they experienced while messing about.
- **Design-based experiments and poster presentations:** Groups systematically explore design variations to learn more about factors (variables) affecting the working of their designs. When software is integrated, it is integrated into this step in the sequence of activities. Whether or not learners use the software to investigate or run their investigations in the real world, they are encouraged in this step not only to identify trends in their data but also to ask questions about and use science content already discussed to explain those trends. Investigation is followed by a "poster session" (Kolodner et al., 2003) where learners present their findings, the trends (rules of thumb) they can extract from their data, and their best explanations of those trends. This, in turn, may be followed by another presentation of science content by the teacher and then attempts by the whole group to collaboratively construct explanations for each of the trends based on that content.

- **Design best hovercraft:** Based on what they learn from their investigations and from the investigations of others, groups design and build their best hovercraft. Groups also test and compare the performance of their best hovercraft with other groups' hovercrafts. Water races are also conducted sometimes.
- **Gallery walk:** Learners present their design experiences to each other in a gallery walk (Kolodner et al., 2003), asking their peers to help them explain why their designs did or didn't work and suggest ways of fixing the problems. Here again, learners engage collaboratively in explanation construction.
- **Scaling new levels:** Once groups have their best hovercrafts, they are introduced to harder challenges that test the limits of their designs. For example, in the case of the flying saucer, which performs well on smooth floors and carpets, we asked the learners to see if their crafts could hover over grass. In most cases their designs fail, which motivates a new challenge and sets the context for moving on to address that challenge through the next, more sophisticated, type of hovercraft.

Setup

This study was conducted as part of a science summer camp organized by the Center for Education Integrating Science, Mathematics, and Computing (CEISMC) at Georgia Tech and attracted a socio-economically diverse set of rising 7th and 8th graders (ages 13 and 14) from the Atlanta metropolitan area. One teacher collaborated with the researchers to implement the Hovercraft unit three times in three successive weeks. The teacher was neither an expert in the science content nor an expert at design-based learning. However, she was an excellent and energetic teacher in many ways and enthusiastic about learning to use design as a context for science learning. In each week, we had a different set of learners. There were 16, 13 and 18 participants in Weeks 1, 2 and 3 respectively. Participants in Weeks 1 and 3 seemed similar in terms of their background knowledge and overall developmental capabilities, as evidenced in discussions during Day 1 of each week. Participants in Week 2 seemed less motivated and showed less development in terms of their background knowledge and their ability to learn.

Procedure

Based on the natural differences between participants in the three weeks, we have chosen to compare results in Weeks 1 and 3 to learn about effects of integrating the SHADE software into the learning environment. While we had planned a design study where each week we would have participants use an enhanced version of the software, the software was not working well enough in Week 1 to use it. Comparing the results of Weeks 1 and 3 allows us to compare development of explanation capability among participants with similar backgrounds and developmental capabilities, with and without the scaffolding provided by the explanation tool. Participants in Week 1 received support from the teacher to articulate their explanations, and they ran their experiments in the real world and used paper-and-pencil based tools to capture their explanations. Participants in Week 3 followed the same unit with the same teacher but used the software to run experiments and to articulate their explanations. All the sessions were videotaped using two cameras. The two cameras were positioned such that we were able to capture the whole-class interactions during discussions, presentations, lectures, etc.

Findings and Analysis

To understand SHADE's impact on explanatory discourse, we analyzed discourse during whole-group discussions in Weeks 1 and 3 at the beginning of the week, several times during the week, and at the end of the week (see Figure 4).

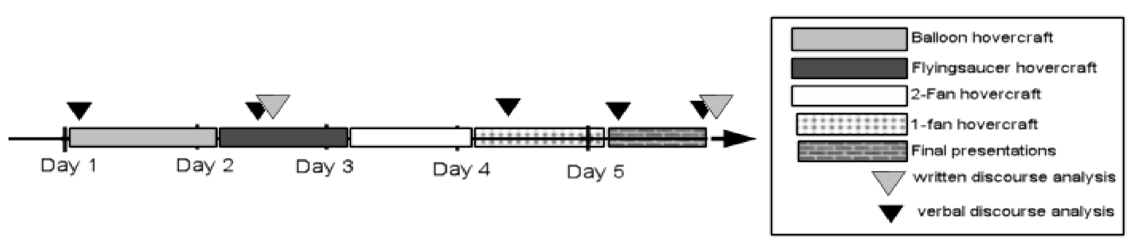

Figure 4: Stages in the unit when discourse analysis was carried out

Discourse analysis at the beginning of the week

Day 1 in both conditions started in a similar fashion with an informal class-wide discussion about what participants already knew about science, engineering, and hovercrafts. Discussions in both weeks were anchored in the question "What does hovering mean?" This discussion was useful in assessing the initial knowledge and explanatory capabilities of participants across the weeks. We found that the discussions during the morning session for both Weeks 1 and 3 were qualitatively similar, consisting of fragmented knowledge of Newton's Laws and ideas about hovering, with minimal continuity of ideas from one participant to the next. This helped us confirm that the baseline for comparison of the two groups was similar.

Written discourse analysis during the week

The written discourse of the participants in Weeks 1 and 3 was analyzed once during the unit and once at the end. The earlier written discourse was what small groups of learners had written on posters in preparation for "poster sessions" where they presented results of balloon hovercraft investigations. We analyzed the written discourse with respect to its form, content, and correctness.

Week 1

(1) ***"****the larger the air, the longer the hovering time*
Why? Because the air is the power."

(2) ***"****The larger the balloon, the longer it hovers and the higher it goes.*
Why - because there is more air that comes out of the balloon and it goes longer."

(3) ***"****The smaller the nozzle, the higher the H[over]T[ime]. The larger the nozzle, the higher the H[over]H[eight].*
Why: when the air passes through a smaller nozzle, the air is more concentrated & blows at a steadier weight, and air passes through a larger nozzle a bust of air lifts the H[over]C[raft] height."

Week 3

(1) *"If hovercraft has a smaller diameter, it will less surface area and a greater hover height.*
IF: CD diameter decreases
THEN: Balloon hovercraft [hover height] increases
BECAUSE:
WHEN CD diameter decreases THEN lift force increase
WHEN lift increases THEN Balloon hove[r height increases]"

(2) *"IF: Nozzle Diameter decreases,*
THEN: Balloon Hovercraft Hovertime increases
Because…
WHEN: Nozzle diameter decreases THEN [Lift] Force decreases
WHEN: Lift force decreases THEN Balloon hovercraft hover time increases"

Looking at the representative explanations above, we see that Week 3 groups structured their explanations as "if X then Y, because when X then A, when A then B … when C then D, and when D then Y". The structure of explanations of Week 1 groups, on the other hand, varied from "since X therefore Y" to "X because Y, and Z". We think the structure of Week 3 explanations was better because participants modeled it on the cause-linking framework modeled for them in the software. When we look at the content of written discourse, the Week 3 groups used more intermediate causal concepts such as net force and lift force in their explanations than did Week 1 groups. We also see that in Week 1, participants typically provided only one-level explanations. As far as correctness is concerned, groups in Week 3 show more correctness. But, that cannot be attributed to SHADE alone because the teacher had improved her understanding of the concepts by Week 3. Therefore, she might have been less misleading in Week 3 than in Week 1. Therefore, we do not take correctness into account in our analysis.

Verbal discourse analysis during the week

We analyzed verbal discourse from 5 whole-class discussions during each week on days 1, 2, 4 and 5 (see Figure 4). The following is an example of verbal discourse analysis of the data gathered from Weeks 1 and 3.

The context for this verbal discourse was the balloon hovercraft challenge, the same one in which the above written discourse analysis was carried out. Groups were asked to investigate ways of making a hovercraft using balloons, bottle caps, and CDs. In both weeks, within thirty minutes, most groups had grasped the techniques needed to assemble a device and had put together a basic working hovercraft. After demonstrating their crafts to each other, the teacher reviewed the scientific method and presented the nomenclature of a hovercraft, including hull, air cushion, cushion pressure, power system, and lift system. It was at this point that discussion during the two weeks diverged. During Week 1, participants conducted design investigations in the real world, and during Week 3 participants used SHADE to conduct design investigations and to (optionally) provide explanations during those investigations. In the poster session that followed in both weeks, groups were encouraged to include results in their posters along with appropriate written explanations. Teacher provided help as needed in both weeks to help participants complete this task. We analyzed the verbal discourse of participants presenting their posters and verbal discourse of any accompanying whole-class discussions.

Our analysis shows that the verbal discourse of participants in Week 1 contained impoverished explanations with respect to science content and focused primarily on the designed artifact. The verbal discourse of participants in Week 3, on the other hand, were more sophisticated and mimicked the explanations that they had articulated using SHADE. A snippet from typical verbal discourse from Week 1 and Week 3 are compared below:

Typical Week 1 explanation
Student: *If I change the size of the balloon it will hover longer.*
Teacher: *... change the" if" statement to make it better*
Student: *If I increase the balloon…*
Teacher: *Good, if I increase the balloon size then it will hover longer.*

Typical Week 3 explanation
Student: *If the lift force is greater than the gravitational force then the net force will be directed upward, but if the gravitational force is greater than the lift force then the net force will be directed downward and the hovercraft would not move.*

A full analysis of the same data shows that the best Week 1 discourse was equivalent to the typical Week 3 discourse, and that the best Week 3 discourse was significantly better than the best Week 1 discourse as depicted below:

Best Week 1 explanations
(1) ***Student1:*** *Because adding weight to the hull is going to push more gravity down and it is going to push the air cushion down and have less air cushion"*

(2) ***Student2:*** *With every action there is an equal and opposite reaction…[so] air under the hull must overcome gravity*

Best Week 3 explanation
Student: *If fan diameter increases then flying saucer hovercraft hover height increases because, when fan diameter increases then the cushion pressure increases. When cushion pressure increases then lift force increases. When lift force increases then net force increases. When net force increases then flying saucer hovercraft hover height increases.*

Discourse analysis towards the end of the week

On the last day of the week, small groups presented their experiences in the camp to an external audience including their family members. The latter part of the morning session of the final day was dedicated to preparing posters for their presentations. Student groups were given a list of topics to choose from for their posters. They were also free to choose their own topics. The content of posters and verbal presentations of groups in Weeks 1 and 3 were compared to analyze the differences in learners' discourse towards the end of the unit. We classified these posters into four categories based on their function, as depicted in Table 1.

Table 1: Classification of final posters and their sample contents

Poster Type	Sample contents
Recommendation posters: Their function was to communicate to the audience how to build a good hovercraft of a particular type. Typically, they contained a list of recommendations with or without associated explanations. Sometimes, the recommendations were captured implicitly in the form of Rules of Thumb.	*"**the best flying saucer needs:*** *maximum hover height, a light weight structure, … , a sturdy body* ***Results from tests:*** *We have concluded that a flying saucer hovers best with 1 battery pack because with 2 ... we concluded that a hovercraft (flying saucer) hovers higher when it has a bumper on the bottom.... Our last conclusion is that 30 grams is a good weight for a flying saucer."*
Investigation posters: Their function was to communicate the results of the experiments conducted to understand the effect of a particular variable (e.g., hull weight, surface area) on the overall performance of the hovercraft. They captured the outcome of the experiments in terms of rules of thumb.	*"ROT: if the surface area increases then the hovercraft hover height decreases.* *Why? If the surface area increases, the cushion pressure beneath the hovercraft will decrease because it will have to support a larger area…"*
Comparison posters: Their function was to communicate the comparison of different designs. They usually contained	*"**Differences in the 1 fan hovercraft and the 2 fan hovercraft*** ***GH1:*** *… one fan is used … to give the craft lift and to push it forward … a ramp is us to direct the air flow under & behind the craft.*

the decisions behind compared designs and any trade-offs with or without explanations.	***GH2:*** *... one fan pushes air down... 2nd fan is placed at the back ... pushes air backwards causing the craft to go forward.* *...* ** The one fan is lighter, allowing the hovercraft to go higher. This is because ...* ** The one fan isn't as forceful as a craft with two fans....* ** The hovercraft with 2 fans is heavier than the hovercraft with 1 fan but the extra power makes up for the extra weight..."*
Description posters: Their function was to communicate description of an object of interest (example – hovercraft, skirt). Typically, they contained description of systems or subsystems in terms of their structural elements and also how they worked. In the context of describing how it works, participants explained the science behind hovercraft design in some cases. Interestingly, description posters can only be found in Week 3.	*"**What in the world is a skirt?*** ** How does it contribute to a hovercraft?* *It increases the cushion pressure underneath the hovercraft ...* ** What makes a good skirt?* *Light-weight durable, ...* ** Difference types of skirts!* *1. Self-inflatable: won't fold under the hovercraft...* *2. Bumper Reinforcement: bumper material ... is put inside...* *3. Tape reinforcement: ... also put in the skirt to make it sturdier."*

To analyze the final posters and presentation, we first counted the total number of statements made that warranted an explanation, including recommendations and rules of thumb. We rated these statements according to simple statements (Type 1), statement with rudimentary explanations (Type 2), and statements with good explanations (Type 3). For example:

> **Type 1:** *"...small [balloon] - has the least power, medium [balloon] - has medium power, large [balloon] - has the most power..."*
> **Type 2:** *"...if the surface area increases then the hovercraft hover height decreases... [because]... the cushion pressure beneath the hovercraft will decrease...."*
> **Type 3:** *"... [Skirt] contributes to the hovercraft ... increases the cushion pressure underneath the hovercraft causing the lift force, net force, and hover height to increase."*

Good explanations (Type 3) contained coherent causal explanations. Rudimentary explanations (Type 2) contained either mere reproduction of formulas without showing any understanding of the formulas or simple explanations without intermediate causal concepts. Simple statements (Type 1) are statements without justification of any sort. Type 3 statements are given the highest rating and Type 1 the lowest.

In Week 1, posters and presentations mostly contained Type 1 and Type 2 statements. The following Table 2 captures the findings from Week 1. As one can see, most statements are Type 2 (8 out of 13, 61.53 %).

Table 2: Results of analysis of Week 1 posters and presentations

	Title	Poster category	Type 1	Type 2	Type 3
A	Hull weight	comparison	0	0	1
B	Surface area	comparison	1	0	0
C	Motor power	comparison	1	2	0
D	1 fan vs. 2 fans	comparison	0	2	0
E	Best flying saucer	recommendation	2	2	0
F	Balloon hovercraft	recommendation	0	2	0
		Total = 13	4	8	1

In Week 3, posters and presentations had significantly fewer Type 1 statements and contained an equal number of Type 2 and Type 3 statements. Table 3 captures the findings from Week 3. Most statements are either Type 3 (5 out of 11, 45.45 %) or Type 2 (5 out of 11, 45.45 %).

Table 3: Results of analysis of Week 3 posters and presentations

	Title	Poster category	Type 1	Type 2	Type 3
A	Difference in 1 & 2 fan	comparison	0	0	2
B	The effect of weight	comparison	0	1	0
C	Surface area	comparison	0	0	1
D	Best flying saucer	recommendation	0	2	0
E	Best balloon	recommendation	1	1	0
F	What's a skirt?	description	0	1	1
G	Hovercraft 101	description	0	0	1
		Total = 11	1	5	5

The consolidated results in Table 4 show the overall differences between Weeks 1 and 3 with respect to the statement types. While 30% of the statements in Week 1 were of Type 1, only 9% were of Type 1 in Week 3. While only 7% of explanations in Week 1 were of Type 3, almost half (45%) in Week 3 were of Type 3.

Table 4: Consolidated results comparing posters and presentation findings across Weeks 1 and 3

	Type 1		Type 2		Type 3	
Week 1	4/13	30.76 %	8/13	61.53 %	1/13	7.69 %
Week 3	1/11	9.09 %	5/11	45.45 %	5/11	45.45 %

Discussion

This study sought to explore the affordances of SHADE as a collaborative explanation-construction tool for enhancing learners' explanatory discourse and explanation construction in the classroom. We hypothesized that the learners who used the explanation-construction tool would engage in better explanatory discourse by the end of the Hovercraft unit in comparison to learners who did not use the tool, even if all received similar teacher support throughout the unit. Our results support this claim because both written and verbal discourse of participants who used the explanation-construction tool in Week 3 was significantly different from that of participants who did not use the tool in Week 1. Specifically, changes were noticed in three areas. First, participants in Week 3 felt the need to explain more. More of their claims and findings were communicated with causal explanations when compared to participants who did not use the tool. Second, participants from Week 3 maintained a more coherent structure in their explanations consistently across groups throughout the unit. Third, the content of explanations from Week 3 was more elaborate and contained more intermediary causal concepts (e.g., lift and net force) compared to Week 1.

How did SHADE impact the learners? The participants in Weeks 1 and 3 had similar knowledge and capabilities at the start of their hovercraft experiences, but the teacher knew a bit more about hovercraft science and design-based learning by Week 3. So there are two possible reasons why the learners in Week 3 might have performed better: the teacher's increased understanding might have influenced the learners' understanding and capabilities and/or use of the software might have been responsible. We have been able to rule out the influence of the teacher because while our analysis showed that there was some improvement in the teacher's understanding of science concepts by Week 3, we did not see a significant impact of this on either her explanatory discourse or her methods of teaching. This suggests that use of SHADE's explanation-construction tool was primarily responsible for the better quality of explanatory discourse among Week 3 participants. Our explanation for the increased number of explanations in Week 3 is that situating SHADE's explanation-construction tool in the context of design investigations gave participants practice *both* in explaining observations and also in identifying opportunities to explain. A possible explanation for the differences in the form and content of the explanations between Weeks 1 and 3 is that learners who received structured explanation support in SHADE developed better conceptual frameworks in which to organize the specific concepts they learned, and the external discursive representation gave participants a better understanding of the form of a good explanation. This account is in line with the foundational literature we drew on in SHADE's design which suggested that explanation support would provide specific guidance about the nature of scientific explanations.

How did SHADE impact the teacher? Although the software had an equal potential to impact the teacher's discourse, SHADE influenced learners more than the teacher during this study. That can be explained by the fact that the teacher did not use SHADE at all. The constant presence of researchers during all the 3 weeks did not necessitate the teacher's use of the tool to integrate it into her teaching. Under normal circumstances, though, we can expect that the teacher would use SHADE before and during the implementation of a unit. This has the potential to influence teachers' discourse as well, in the same way that the software usage influences the learners. We also expect that this change in teacher's discourse will be an additional influence in enculturating the learners into becoming better scientific explainers. A useful extension of this study would combine the kind of analysis presented here with discourse analysis of teachers in the classroom after they actively use and integrate the SHADE software.

A software tool like SHADE makes a difference in how learners and teachers engage in collaborative learning to become better scientific explainers. Our in-depth discourse analysis suggests that external discursive representations embodied in the explanation-construction tool affect collaborative knowledge construction. Our results have implications for learning and instruction in design-based learning environments. Often, teachers' lack of expertise in facilitating knowledge construction in such environments hampers development of scientific understanding among learners. Our hypothesis is that enculturating learners and teachers into explanation construction in the context of design-based investigations promotes such scientific understanding through collaborative knowledge construction, and our results suggest that a tool like SHADE that models appropriate discourse has an important role to play as a mediational resource in facilitating collaborative interactions in the classroom.

Acknowledgements

This research was supported in part by a grant from the National Science Foundation. We wish to thank Eric Goldstein, Tony Docal and Megan McCollum for their support in this research effort.

References

Bell, P., & Linn, M. C. (2000). Scientific arguments as learning artifacts: designing for learning from the web with KIE. *International Journal of Science Education*, 22(8), 797-817.

Coleman, E. B. (1998). Using Explanatory Knowledge during Collaborative Problem Solving in Science. *Journal of the Learning Sciences*, 7(3/4), 387-427.

Kolodner, J. L., Camp, P. J., Crismond, D., Fasse, B., Gray, J., Holbrook, J., Puntambekar, S., & Ryan, M. (2003). Problem-Based Learning Meets Case-Based Reasoning in the Middle-School Science Classroom: Putting Learning by Design™ Into Practice. *Journal of the Learning Sciences*, 12(4), 495-547.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge, England: Cambridge University Press.

Roschelle, J., & Teaslay, S. D. (1995). The construction of shared knowledge in collaborative problem solving. In C. E. O'Malley (Ed.), *Computer supported collaborative learning* (pp. 69–97). Berlin: Springer-Verlag.

Roth, W.-M. (2001). Situating cognition. *Journal of the Learning Sciences*, 10 (1/2), 27–61.

Ryan, M. T. & Kolodner, J. L. (2004). Using 'Rules of Thumb' Practices to Enhance Conceptual Understanding and Scientific Reasoning in Project-Based Inquiry Classrooms. *Proceedings of the International Conference of the Learning Sciences 2004*, (pp. 449-456). Los Angeles, CA: Lawrence Erlbaum Associates, Inc

Sandoval, W. A., Crawford, V.M., Bienkowski, M., Hurst, K., & Millwood, K. A. (2003). *Effects of explanation support on learning genetics*. Paper presented at the annual meeting of National Association for Research in Science Teaching 2003, Philadelphia.

Sandoval, W. A., & Reiser, B. J. (2004). Explanation-driven inquiry: Integrating conceptual and epistemic supports for science inquiry. *Science Education*, 88, 345–372.

Scardamalia, M., & Bereiter, C. (1994). Computer support for knowledge-building communities. *Journal of the Learning Sciences*, 3(3), 265-283.

Suthers, D. D., & Hundhausen, C. D. (2002). The effects of representation on students' elaborations in collaborative inquiry, In G. Stahl (Ed.), *Computer support for collaborative learning: Foundations for a CSCL community. Proceedings of CSCL 2002* (pp. 472-480). Mahwah, NJ: Erlbaum.

Toth, E., Suthers, D., & Lesgold, A. (2002). Mapping to know: The effects of representational guidance and reflective assessment on scientific inquiry skills. *Science Education*, 86, 264–286.

Vattam, S. & Kolodner, J. L. (2006). Design-based science learning: important challenges and how technology can make a difference. *Proceedings of the International Conference of the Learning Sciences 2006*, (pp. 799-805). Bloomington, Indiana: Lawrence Erlbaum Associates, Inc.