On foundations of technological support for addressing challenges facing design-based science learning*

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Design experiences can provide valuable opportunities for learners to improve their understanding of both science content and scientific practices. However, the implementation of design-based science learning (DBSL) in classrooms presents a number of significant challenges. In this article we present two significant challenges, bridging the design-science gap and overcoming time and material constraints, and a strategy for addressing them through software design in which explanation-construction scaffolding integrates with modeling and simulation. We present two software systems (SIMCARS and SHADE) developed based on our strategy and guidelines for integrating them into DBSL practices. We present a pilot study (involving SIMCARS), the findings of which support the potential of our technology for responding to the identified challenges. A follow up study (involving SHADE) is presented which shows the affordances of our technology for improving the quality of classroom discourse, suggesting the potential of our strategy to enhance collaborative understanding and social construction of knowledge in DBSL environments.

Keywords: design-based learning, knowledge construction, science education, technology-based scaffolding, simulation and modeling, external representations

1. Introduction

Learning science through design activity has been shown to be a productive way to promote deep science learning (Hmelo et al. 2000; Kolodner et al. 2003; Penner et al. 1998; Resnick 1996; Fortus et al. 2004). In design-based science learning (DBSL), the goal of designing a working artifact contextualizes all inquiry learning. Design is used as a vehicle through which scientific knowledge is constructed and real-world problem-solving skills are cultivated. The design challenge provides...
impetus for identifying what needs to be learned and for sustaining engagement in inquiry over time, as well as providing need for cultivating and using a variety of skills.

But while learning science through design activity can lead to deep science learning, not all teachers are expert at facilitating its enactment, and even in classes where the teacher is proficient, not all students are able to connect their design experiences to generalized science concepts (Kolodner et al. 2003; Ryan and Kolodner 2004). There are a variety of reasons for this. Some students need more time and opportunities experiencing a concept, attempting its application, and using it for explanation than there is time for in a classroom; some students need more variation across those opportunities; and some need more guidance than might be available. In these situations students can still be successful at completing a design challenge without gaining targeted scientific understanding.

A variety of approaches have been tried to alleviate these problems, some in the context of design-based learning and some in other inquiry contexts: (i) introduction of software that scaffolds and allows simulation of phenomena under a variety of conditions, usually with animated graphical visualizations (e.g., Thinkertools (White 1993), SimQuest (Van Joolingen and De Jong 2003), RIDES (Munro et al. 1997)); (ii) use of modeling software that scaffolds and allows learners to model situations on the computer rather than in the real world (e.g., ModelIt (Soloway et al. 1996), StarLogo (Resnick 1994), Articulate Virtual Laboratory (Forbus et al. 1999)); and (iii) introduction of software that encourages articulation and provides scaffolding as students are attempting explanation construction (e.g., ExplanationConstructor (Sandoval 2003; Sandoval et al. 2003)) or argument articulation (e.g., Belvedere (Suthers et al. 1995)).

But none of these approaches are entirely consistent with the intentions of design-based learning. Simulation systems usually focus on targeted scientific phenomena but not on their application in the context of the design challenge students are working on. Contrary to design-based learning, where learners are building tangible artifacts, model-building systems usually focus on modeling systems that are impossible for a learner to experience closely or manipulate firsthand (e.g., an ecosystem or a chemical production plant). The major deficiency of software for scaffolding explanation is similar. No software for scaffolding explanation has been designed with design-based learning in mind. In the best of those systems (e.g., ExplanationConstructor (Sandoval 2003; Sandoval et al. 2003)), learners are asked to give causal accounts of observations after they have been introduced to the science content. In a DBSL situation, however, learners are motivated to predict and explain the behavior of artifacts they are designing based on incomplete scientific understanding as well as incomplete understanding of what a good explanation is.
Our broad research goals are twofold. With respect to technology, we want to (i) understand the functions simulation and modeling software should have when integrated with design-based learning and (ii) provide guidelines for designing the interactions between learners and the software for ease of use and to promote personal and epistemological connections among learners. With respect to learning, we wish to understand which practices for interleaving physical design and testing with computer simulation, modeling, and explanation scaffolding will result in deep science learning among learners. Our efforts have been focused on middle-school (grades 6 to 8) learners.

Within this broader context, and in this article, we address some narrower goals: to articulate two of the significant challenges to implementing DBSL in classrooms, bridging the design-science gap and overcoming time and material constraints; to identify guidelines for designing software to address those two challenges; to begin to identify strategies for integrating such software into DBSL curricula; and to identify specifics about the affordances of such software for promoting science learning in DBSL environments and the challenges that remain. We present two studies. A pilot study conducted in spring 2005 supports the potential of such software for responding to the two identified challenges. A more formal study showed the same potential using a different curriculum and different version of the software and further showed affordances of such software for improving the quality of classroom discourse, suggesting its potential to enhance collaborative understanding and social construction of knowledge in design-based science classrooms.

2. Design-based science learning: Promises and challenges

In design-based pedagogy, the goal of designing a working artifact contextualizes all curricular and inquiry activities (e.g., Kolodner et al. 2003; Fortus et al. 2004). Design-based science pedagogy, at its best, presents students with a design challenge that requires, for its success, using some targeted science content and scientific reasoning to design and build a working device. While attempting to understand the design challenge, and perhaps during first attempts to achieve the challenge, students identify the science content they need to apply for success, and they move between learning that content and applying it to achieve the design challenge. In the best of enactments, learning is active, expertly facilitated by the teacher, and includes opportunities for publicly articulating science understanding, debating understandings, explaining phenomena, and debugging those explanations. In such an environment, as students iteratively move toward better design solutions, they iteratively move toward better understandings of science
concepts and laws, generalizing from the particular experiences they are having as they design.

But research shows that generalization from experiences of particular phenomena or devices to broader science concepts and laws does not always happen naturally (Crismond 2001; Kolodner et al. 2003; Ryan and Kolodner 2004). Design challenges can often be achieved to a degree that students (and teachers) find them satisfactory without students making this progression from particular to general. Because of this we have had to devise strategies to bridge the gap between (i) design — the concrete world of direct experiences and creation of products and (ii) science — the abstract world of physical laws and causal explanation, i.e., between (i) the phenomena they are experiencing and trends they see and (ii) the science that explains those phenomena and trends.

2.1 Learning by Design™: Fulfilling the promises of DBSL

Our own research group has developed an approach to DBSL called Learning by Design™ (LBD) (Kolodner et al. 2003) that orchestrates classroom activities in ways that afford the kinds of facilitation and scaffolding needed so that the affordances of DBSL will be fully realized.

![The Learning by Design cycle](image)

*Figure 1. The Learning by Design cycle*

Each LBD unit begins by introducing students to a design challenge. The students work in small groups, *messing about* with materials or devices that will help them understand what they need to learn to successfully achieve the challenge. They get together as a class around a *whiteboard* to share their experiences and ideas for achieving the challenge and to articulate what they need to learn for success. From there, the class decides which are the most important of the questions and divides into small groups, each of which designs and runs an investigation aimed at answering their question. Students report to each other in a *poster session* about their methods and results, and peers ask questions and make suggestions. *Design*
rules of thumb are generalized from their investigation results to help learners connect the science they are learning to its application. Then groups move on to making a first pass at achieving the challenge. The groups present their design ideas to the class in a *pin-up session*, reporting to the class about their design decisions, why they think each is a good one, and predicting how their design will behave when constructed. Then they move on to constructing and testing their designs. Finally, students present their experiences to each other in a *gallery walk*, soliciting feedback from others which could lead to more questions and additional investigations. This cycle, shown in Figure 1, is repeated until an appropriate degree of success is reached.

Within this sequencing are embedded a number of strategies for promoting science learning. One such strategy is our Rules of thumb (RT) practice (Crismond et al., 2001; Ryan and Kolodner 2004), designed to serve the *cognitive purpose* of generalizing a theory from observations and broadening its context, and the *design purpose* of making those abstract laws more usable in the context of designing. The RT practice involves, first, identifying trends in experiments in terms of rules of thumb (e.g., the larger the surface area of the canopy, the longer time it will take for the parachute to fall). Before moving on to use those rules, the teacher asks why a rule of thumb might be true. This provides an opportunity for learners to associate scientific explanations with the observed trends in their experiments, and it provides a *need* for them to visit relevant science content. Students then plan their designs based on the identified rules of thumb and use the explanations associated with those rules to describe the reasons behind their design choices. As such, the RT practice has students generate trends that need to be explained, work towards explanations, use those rules and explanations to predict outcomes, and then, as the rules and their explanations are applied, iteratively revise their explanations. This practice is consistent with what is recommended by other studies in science education. Studies show that making explanation demands of inquiry explicit can improve students’ efforts in inquiry (Dunbar 1993; Schauble et al. 1995).

2.2 The challenges

Our studies show that even rudimentary implementation of the RT practice in the LBD-style classrooms results in science learning that is more advanced than that of students in comparable non-LBD classrooms (Kolodner et al. 2003). Further, our studies show that differences in the way the RT practice is implemented can produce differing outcomes in student learning (Ryan and Kolodner 2004). Students who participated in better implementations of this practice showed a better understanding of the targeted science concepts and demonstrated better applicability of those concepts to their designs than those who engaged in a ver-
sion of the practice that focused less rigorously on connecting their experiences to the targeted science. The more the teacher had students revisit and refine their explanations of the rules of thumb, the deeper was their science learning.

Additionally, the success of the RT strategy depends significantly on the quality of the rules of thumb generated by the students with the help of their teacher. The best rules of thumb and best science learning we identified were in the classrooms of a teacher who orchestrated the elements of the practice well and guided the classroom participation based on her deep understanding of the science (Ryan and Kolodner 2004). She was fluent enough with the science to help the learners diagnose their “troubled” designs from a science perspective, and she created an environment where students found it meaningful to generate rules of thumb and understood the purpose of generating those rules. But not all teachers can do this well.

Another set of pragmatic challenges for design-based learning also shows itself in our evaluations of LBD. Because there is only limited time in a classroom to cover any specific science topic, the speed with which learners can construct and then refine their designs greatly effects the number of experiences they will have revisiting and refining the science. Furthermore, noise in the real world combined with students’ novice construction capabilities lead to difficulties collecting fully consistent and precise enough data needed to identify the trends. In addition, the real world does not easily provide the variety some students need for understanding. For example, in one of our units dealing with the design of model cars, students can experience the effects of 2-inch wheels and 5-inch wheels, but they cannot easily experience the effects of other sizes. They can put 3 balloon engines on a vehicle, but they cannot build one with 6 engines because it is too hard to blow up 6 balloons at the same time.

Our investigations show that the better these two challenges, bridging the design-science gap and overcoming time and material constraints, are addressed, the better students will learn science content and scientific reasoning from their DBSL experiences.

3. Addressing DBSL challenges through software assistance

Our software challenge, then, is this: Can we devise a technological innovation (or a set of them) that addresses these challenges — (i) sharing with the teacher some of the burden of helping learners bridge the gap between design experiences and scientific explanations and (ii) allowing for more varied and more exact experiences? If so, what should the nature of this technology be? What features should it have? When, where, and how should it be used? Two classes of technology seem
well suited for addressing these challenges if they can be integrated with each other and with other classroom activities in effective ways — explanation-construction tools and simulation and modeling tools.

3.1 An explanation-construction tool to bridge the design-science gap

One can think about enhancing students’ experiences connecting physical phenomena to scientific explanations by providing software tools that will scaffold their ability to explain phenomena they experience. They might use such a tool after they have derived rules of thumb and wish to attach scientific causes underlying their rules. This would expose students to the relevant science and to connecting science to experienced phenomena (i.e., bridging design-science gap). It might also promote discussions of science concepts among classmates during group presentations and whole-class discussions, which are otherwise more design focused.

Studies have shown such beneficial effects of using software-based explanation-construction tools (e.g., Sandoval et al. 2003; Bell and Linn 2000; Suthers et al. 1995). From that research, we can derive some guidelines for including explanation activities in our design-based curriculum and for developing technology for aiding students to become better explainers and better learners in the process. (i) It is important for the students to understand the goals for the products that their inquiry processes are intended to produce. With respect to the explanations, this means that students must understand that scientific explanations are efforts to construct causal accounts for how or why things happen. (ii) A technology designed to scaffold explanation generation should provide both domain-general and domain-specific supports. At a domain-general level, the tool should help students to satisfy criteria of good explanations: they should capture causality, they should be parsimonious, and they should account for observations. At a domain-specific level, the tool must provide explanation templates that visually represent a framework of domain concepts, presented as a chain of causally connected components. (iii) It must encourage students to support explanations with specific data, by providing facilities to link data generated in their investigations to specific explanation components. (iv) It must encourage students to explicitly consider alternative explanations and question which is best. (v) It must help students recognize the limitations of specific explanations. (vi) It must provide avenues for explanation evaluation via critiquing, to encourage students to reflectively evaluate their work using the criteria mentioned above.
3.2 Simulation and modeling software to overcome time, materials, and other environmental constraints

One can think about enhancing students’ experiences with designing and testing physical artifacts with the opportunity to do further exploration of like artifacts on the computer in a simulation and modeling environment. But simulation and modeling environments provide rich and engaging learning experiences only under certain conditions. Papert (1993) and Resnick et al. (1996) suggest that it is crucial to design such environments taking into account the need for learners to be engaged in activities that are personally meaningful and that promote epistemological connections. In our context, personally meaningful has two parts to it. First, models and simulations should connect to learners’ interests and passions, generating learner interest in engaging with them. Second, learners have to be able to easily sense the connections between models they are manipulating within the software and real world experiences. Epistemologically meaningful means that when they run their model or test their design, its failures raise questions for them that they can handle by using the domain concepts. Failure has to be just beyond their capabilities, within their zone of proximal development (Vygotsky 1978). Experience with simulation manipulatives, however, shows that it is quite difficult to design toolkits that themselves provide a complete set of learning affordances for all learners. Rather, as we have found in our LBD classrooms, additional help is usually needed from outside the software for many learners.

Examination of the larger literature on simulation and modeling for promoting learning suggests to us three guidelines for designing the simulation and modeling portion of our software. (i) Software to be integrated into a design-based learning environment should focus on both model building and simulation. (ii) Modeling and simulation systems for integration into design-based classrooms should be built so that at least some of their primitive elements match the parts of the physical artifacts learners are already manipulating. (iii) Modeling software to be integrated into design-based learning environments should include in it facilities for helping learners learn from their modeling experiences. This means helping them decide what explorations to make next, remember why they were making those explorations, make predictions about the behavior of their model before running it, explain the model’s behavior after running it if the behavior is different than what was expected, and recording and saving their experiences in a way that they can easily understand and easily access later.
3.3 Integrating the two software functionalities

These guidelines for designing software environments effective for promoting science learning in DBSL environments suggest ways of integrating explanation-construction scaffolding with simulation and modeling functionality. The guidelines suggest that explanation construction should be directed by the investigation and design revision goals of learners. That is, explanation construction should be situated in the context of design questions and design consequences learners are investigating. Such integration affords asking learners to provide explanations at times when it feels like explanations are authentically needed. They can be asked for predictions when they set up a design investigation and be prompted to explain their predictions. They can be asked to identify what they learned through that investigation and be prompted to generate accurate explanations by comparing their predictions with what actually transpired. This brings goal-orientedness to learners’ use of science because scientific explanation is situated in the context of issues they are investigating.

Our approach recommends integrating software into the design-based curriculum with the purpose of enhancing real world investigation and design activities. We do not intend to imply that software should substitute for those activities. Designing and conducting experiments on real artifacts has significant value for learning. Producing tangible artifacts is sometimes more motivating and promotes a deeper sense of having actually “made” something. Also, interaction with real world artifacts affords feeling and sensing effects of variations in more tangible ways. Further, real world provides more manipulability, thus allowing more subtle and creative variations in solutions. Through our investigations we want to learn how exactly to integrate software modeling and simulations with physical modeling and testing in ways that promote the affordances of both.

4. The plausibility of proposed software solution: A pilot investigation

The objective of our pilot study was to put our design principles into a software design and to integrate it into a DBSL environment to learn more about its feasible use. Some of the research questions for this study were: (i) how does integrating a simulation and modeling-based virtual design environment implemented according to our guidelines contribute to the learning experiences of learners; (ii) how well does the design and use of an explanation-construction tool implemented according to our guidelines help learners generate good explanations, and (iii) how well does the practice of explanation generation though such a tool contribute to the bridging of the design-science gulf among learners and contribute towards
enhancing scientific understanding? We designed and built our first software environment, SIMCARS (Vattam and Kolodner 2006), to be integrated into LBD’s Vehicles in Motion (VIM) unit (Kolodner et al. 2003), which focuses on learning about forces and motion in the context of designing miniature vehicles with propulsion systems.

4.1 Context of the investigation: The Vehicles in Motion unit

The design challenge of Vehicles in Motion (VIM) involves designing and constructing a model car and its propulsion system that will travel as straight as possible and cover the longest distance possible within a single run. Throughout the unit, students test several engines to propel the car across a test track that has varying surfaces and small hills. The unit is designed such that in each of its modules, students are addressing engineering challenges associated with making the vehicle function as it should and in that context are investigating science issues that will help them address those engineering challenges. Initially in the unit, a grand challenge is presented to the students — to design a vehicle and its propulsion system that can go over several hills and then travel straight and long under its own propulsion. Learners mess about with toy cars to identify the criteria and constraints of their challenge, what they already know about propulsion and forces, and questions they will need to answer to achieve the challenge. Then, students attempt to make a car powered by a ramp travel as far and straight as possible. This mini-challenge (Coaster Car Challenge) provides a context for answering questions about how to make a vehicle go long and straight, with a need to understand gravity and friction as forces and how forces interact with each other. Next, the students attempt to make a car powered by a balloon engine travel as far and straight as possible. They attempt to run this car over a test track made of carpet and containing small hills. This mini-challenge (Balloon Car Challenge) provides a context for answering questions about how to get a vehicle started and how to keep it going, providing the need to better understand the ways forces interact with each other and for grasping issues of equal and opposite forces. Upon attempting to run their designs over a hill, learners realize they still have more to learn about combining forces in such a way that they can generate enough forward force for their vehicle to counter the force of gravity as it goes up a hill. Next, students investigate the behavior of cars powered by rubber-band and falling-weight engines and test them under similar conditions. Finally, they bring together what they have learned to design a car with a hybrid propulsion system. Table 1 summarizes the science concepts targeted by each learning module. In each module, students follow the LBD cycle (Figure 1) and adopt the various LBD practices discussed in Section 2.1.
Table 1. Concepts addressed in various modules of the *Vehicles* unit

<table>
<thead>
<tr>
<th>Module</th>
<th>Science concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coaster car</td>
<td>Gravity, Forces, Friction, Newton’s First Law of Motion, Velocity</td>
</tr>
<tr>
<td>Balloon car</td>
<td>Acceleration, Force, Net Force, Newton’s Second and Third law</td>
</tr>
<tr>
<td>Rubber-band car</td>
<td>Newton’s Laws of Motion, Torque, Friction</td>
</tr>
</tbody>
</table>

### 4.2 The design of SIMCARS software

In accordance with our technological strategy for addressing the challenges involved in implementing the VIM unit (see Sections 3.1 and 3.2), SIMCARS includes two main functions: (i) a simulation and modeling-based virtual design environment where the students can quickly design and test virtual model cars, and (ii) an explanation-construction tool that scaffolds construction of scientific explanations in the context of designing.

SIMCARS’ virtual design environment: A learner can interact with SIMCARS’ design environment in two operational modes: Explore and Experiment.

Explore mode supports *messing about*, helping learners become familiar with the design space. Through guided play, learners come up with potential design possibilities and questions they need to investigate. Exploring possible designs generates design-related issues and science-related questions to be investigated in greater detail. In a typical classroom session, students explore at most three or four design variations. Exploring designs in SIMCARS’ environment affords quicker and more expansive *messing about* than when done with physical models, leading to more opportunities for inquiry. As shown in Figure 2a, learners can quickly configure a car in SIMCARS by clicking on the various parts of the car and adjusting their parametric values. As shown in Figure 2b, learners can also easily test the performance of their model under a variety of different conditions, some of which are not available in the real world (e.g., zero gravity, zero friction). Learners can also compare two or more designs with the help of relevant visualizations (Figure 2c).

![Figure 2. The Explore mode in SIMCARS: (a) Design area, (b) Test area, (c) Design comparison area](image-url)
Compared to exploration, experimentation is more structured and hypothesis-driven. Here, once a question to be investigated is identified, being able to design and run an experiment and get reliable results is desirable. But neither is completely achieved in classrooms because real world construction takes time and the real world is inherently complex and noisy. Interaction with SIMCARS in the Experiment mode takes the user sequentially through steps involved in designing and running an experiment: (i) capturing the question being investigated (Figure 3a), (ii) setting up an experiment by configuring a control design and a test design (Figure 3b), (iii) predicting the outcome of the experiment and explaining the scientific reasons behind the prediction (Figure 3c), and (iv) running the experiment and getting feedback on the outcome of the experiment (Figure 3d).

SIMCARS’ Explanation-construction tool: The explanation-construction tool consists of an explanation template that serves as an external discursive representation (Sandoval et al. 2003). A discursive representation is one that represents elements of an explanation. Scaffolding for explanation construction in this tool takes the form of partially filled templates (Figure 3e). Each template captures a portion of the mechanism behind what will be observed in the form of cause-linking statements. For example, “friction in the control car is less than friction in the variable car; therefore, net force experienced by the variable car is less than the net force experienced by the control car; therefore, the acceleration of the control car is greater than the acceleration of the variable car;...” Providing the right explanation is reduced to completing an explanation template. Further scaffolding is provided through menus of terms for filling the unfilled blanks in the template, allowing multiple-choice selection. The explanation templates and menus of terms match the science content of the Vehicles unit.

Integration of SIMCARS into the Vehicles unit: We determined that experiments would provide a good context for learners to engage in explanation activity because this is a key activity where they systematically investigate the effects of structural changes in their designs. The explanation-construction tool would be best launched in the Experiment mode, between step 2 (after setting up the control and test designs (Figure 3b)) and step 4 (before seeing the outcome of the experiment (Figure 3d)), in accordance with the integration strategy outlined in Section 3.3. Upon launching, the explanation-construction tool helps students make predictions about the outcome of their experiment. For instance, they would predict that “the control car will go farther than the test car.” Then there is an option for them to explain their prediction. If they choose to explain, the explanation tool scaffolds them in generating an explanation. They then run their experiment and see results as well as visualizations of important phenomena (size of forces, speed, etc.) They run the explanation tool again to help them identify trends in their data and to explain expected and unexpected results.
4.3 The pilot study details

We conducted a pilot study using SIMCARS in the context of the Vehicles unit in spring 2005. The study was conducted as part of an after-school program in a suburban independent school. Participants were 16 6th graders (ages 11–12),
all of whom volunteered to participate with permission from their guardians. We
implemented a short version of the VIM curriculum, making sure the adapted ver-
sion retained the “flavor” of the original unit. Students focused on the Coaster Car
Challenge to learn about forces, friction and gravity and then on the Balloon Car
Challenge to learn about combining forces.

Learners built a physical car as a first pass of the messing about activity. They
then explored design variations in SIMCARS’ design environment in Explore
mode. Learners then discussed the different factors that seemed to affect the per-
formance of their cars and identified which factors they wanted to investigate in
detail. They conducted experiments to investigate these factors using SIMCARS in
Experiment mode. Using SIMCARS, they gathered evidence, created and justified
design rules of thumb, and provided explanations using the explanation-construc-
tion tool. Students then engaged in design in the physical world after collecting
and interpreting data as they would have in the original Vehicles unit, and they
built, tested, and revised their vehicles to address each of the challenges.

As suggested by LBD, students moved back and forth from small-group ex-
ploration, investigation, interpretation, building, and testing activities to full-class
presentations and discussions. The teachers for this implementation were two re-
searchers, the first author of this article being one of them. Though not experienced
teachers, they did their best to facilitate small-group work and class discussions as
an experienced teacher would. Data was collected in the form of video recordings
of the sessions and retrospective field notes written by the instructors/researchers
immediately after each session. Video recordings consisted of all whole-class dis-
cussions, all discussions of small groups while testing and attempting to explain
their vehicles’ behavior on the test track, and other small-group discussions on an
ad-hoc basis. Data analysis focused on student discourse. Those utterances dealing
with design concepts, science concepts or both were identified as “science talk”
and noted. Patterns of science talk during each session were identified (e.g., design
talk only, design talk grounded in scientific explanations). Then changes in the
patterns of science talk were tracked over time.

4.4 Preliminary findings

Use of SIMCARS enhanced science talk: During initial stages of the unit, consis-
tent with the “design-science gap” problem mentioned above, we noted from data
that some students were indeed “lost” in the world of design and did not relate
their design activities to the science concepts underlying their designs. Their de-
signs were more informed by trial and error than by their conceptual understand-
ing. We inferred this based on student discourse about their design decisions and
rules of thumb during whole-class and small-group discussions. For instance, in
response to an instructor’s question about why one choice of axle-wheel arrangement (axle is fixed and the wheels spin around the axle) was better than the other (wheels and the axle spin as a single unit within a straw acting as a bearing), the student replied:

Student: … because with the wheels spinning instead of the axle, [it] will create more friction, because spinning of the wheel will [create] friction with the axle. Then the car slows down.

As the sessions progressed, however, science talk became more sophisticated. In sessions following investigation using SIMCARS, we found that the explanations were not only maturing, but also that students’ “science talk” mirrored the explanations elicited from them using SIMCARS’ explanation-construction tool. That is, when students were trying to explain some of their design decisions or rules of thumb, they naturally incorporated the structure of discourse that was present in the templates of the explanation-construction tool. For instance, after SIMCARS was deployed, in response to an instructor’s question regarding why a group made a bearing’s length shorter, the following conversation with the same student ensued:

Student: … they rub against the nut, against the wheel, which is bad, [be]cause the rubbing causes the friction.
Instructor: We’ll know what happens then, right?
Student: the car won’t go very far
Instructor: why?
Student: well, if the friction is more, the car has less force pushing it on the ramp compared to a less friction car, causing less speed up. So, when the car comes off the ramp, it carries less speed with it.
Instructor: So less speed means
Student: less speed means less travel, car doesn’t go that far.

Portions of the above explanation maintained the cause-linking structure present in the explanation-construction tool (see discussion on explanation-construction tool in Section 4.2). This case of a student’s explanation discourse mirroring the format of templates in the explanation-construction tool was impressive on two accounts. First, it happened in the context of whole-class discussion, i.e., outside of the context of the tool (indicating transfer). Second, it happened naturally — during whole-class discussions students were free to structure their discourse in any way they wanted.

To summarize, our analysis showed that the reasons and explanations offered by at least some students incorporated appropriate scientific vocabulary after they used the explanation-construction tool. This was in accordance with our prediction about the effects that “bridging” design and science would bring about.
SIMCARS promoted more design-space exploration and more question asking: It is not possible for us to accurately know how many designs every group explored using SIMCARS. But we closely followed one group’s messing about activity, with and without SIMCARS. Using SIMCARS, that group explored twelve different variations of designs during one session, compared to three or four when working with physical models. More extensive exploration of the design space also helped at least some students in their discovery of variables affecting the performance of their vehicles. For example, early in the Balloon Car Challenge, students constructed and tested their first physical versions of their cars. In the classroom discussion that followed, we asked them to identify the variables that affected their vehicle designs. They were able to identify only two variables — the number of balloons on the engine, and the number of straws forming the nozzle of the balloon engine — both easily perceivable. The actual number was at least four. They had left out the length of the straws (nozzle) and the number of layers of balloons. The SIMCARS exploration activity followed. In the discussion that followed that, students identified all four variables. Using SIMCARS, learners explored more of the design space and were able to identify more factors that cause variation and are worth investigating.

4.5 Discussion

Our pilot investigation results suggest that integration of a software tool designed according to our guidelines into a DBSL learning environment will have a positive impact. The benefits of using the virtual design environment helped our participants meet some of the difficult challenges of learning from design activity in a shorter period of time, addressing one of the challenges that we identified earlier — overcoming time, material, and other environmental constraints.

Our results also suggest that the design and integration of SIMCARS’ explanation-construction tool has the potential to provide the necessary connections between science content and design activity, addressing the design-science gap. Some students who used this tool demonstrated deeper understanding even though the facilitation was handled by inexperienced instructors. Further, their “science talk” mirrored the explanations that they gave using the explanation-construction tool. This was an important side effect of using the explanation-construction tool that we investigated further in our next study.
5. A Formal investigation: How might use of an explanation-construction tool influence classroom discourse?

Our pilot study showed the feasibility of continuing our line of research. It showed that at least one way of implementing the design principles articulated in Section 3 of this article had the potential to positively affect learning from design-based activities in science class. But that investigation was carried out over a period of time too short for us to see or collect evidence of deep and lasting learning. In that short time, however, we were able to see the beginning of explanation capabilities developing among students. Students’ mirroring of the science talk patterns from the software seemed significant to us. It suggested that providing patterns for explanatory discourse to students would begin to scaffold their explanation capabilities, which in turn provided the necessary connections between science content and design activity. We sought to investigate that more closely. Would an explanation-construction tool influence classroom discourse in predictable ways? If we introduced explanatory discourse more systematically, what specific effects would that have? Would the classroom discourse be more systematic? Would it contain more or better causal explanations?

These questions hold two-fold interest. First, if indeed we find that an explanation-construction tool positively influences the classroom discourse by bringing in more systematicity in terms of including more causal explanations, we can hypothesize that it will lead to better collaborative learning in DBSL settings. Second, discursive representations have been a subject of much study in the context of scientific knowledge construction (Bell and Linn 2000; Sandoval et al. 2003; Scardamalia and Bereiter 1994; Toth et al. 2002; Vattam and Kolodner 2006). A majority of those studies, including our earlier SIMCARS research, have focused on its role in constructing understanding among learners, either in solitary or small group setting. Only some of them have examined the role of such representations as mediational resources (Roschelle and Teasley 1995) facilitating classroom-wide collaborative interactions. Suthers and Hundhausen (2002) reported the effect of representations of argument structures on learner discourse in the context of within-group collaboration. Perhaps we would be able to show the same for our representations, but on a classroom-wide basis.

We carried out this investigation in the context of an intensive week-long design-based unit on hovercraft science. We created a short LBD-type unit for a science summer-camp and the software (called SHADE) to go with it. We chose hovercraft science for two reasons. First, it is appealing to middle-school students, both boys and girls. Second, we had available to us kits from a company called Goldstein Hovercraft that make it relatively quick and easy to design, test and refine hovercraft models. We first provide an overview of the Hovercraft unit. Then we present the design of SHADE. We then present the study.
5.1 Context of investigation: The Hovercraft unit

Hovering around GeorgiaTech was developed to teach physics concepts related to hovercrafts and to teach explanatory practices of designers and scientists. This one-week LBD unit was broken down into four hovercraft design challenges that increased in complexity. Participants designed a balloon hovercraft, a flying saucer hovercraft, a 2-fan hovercraft, and a 1-fan hovercraft. Figure 4 shows typical models of each kind. This was followed by a final presentation to an external audience at the end. The sequence of activities for each mini-challenge was similar to the sequencing in each of the modules of the Vehicles unit.

5.2 The design of SHADE software and its integration into the Hovercraft unit

The design of SHADE is similar to its predecessor, SIMCARS. To bridge the design-science gap, SHADE was developed to promote specific “explanation-construction” interactions in the classroom culture and in the context of learners’ design and investigation needs. To overcome time and material constraints, its virtual design environment imitates the real world in a way that both expands the design space for the learners and allows for more efficient exploration of the space. SHADE incorporates a simulation-based virtual design environment, in which learners can explore variations of the four hovercraft designs mentioned above.
The virtual design environment of SHADE has a design area and a test area. Figure 5a shows the design area in SHADE where one can see the correspondence between virtual crafts and the real models depicted in Figure 4. 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 5b shows the test area. Learners can test their design in the test area, which animates the behavior of their design and shows a graph that plots the hover height versus the hover time. They can also pause and step through the simulation.

The explanation-construction tool in SHADE is embedded in the design comparison feature of SHADE. The Design comparison feature of SHADE (Figure 6a) is analogous to the Experiment mode in SIMCARS with one difference — in SHADE, one can compare multiple designs side-by-side as opposed to only two in SIMCARS. After choosing the designs for comparison, learners have the option...
of (i) predicting the outcome of running those designs side-by-side, and (ii) 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 “D3 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 6b 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. The design of SHADE’s explanation-construction tool is similar to that of SIMCARS and includes partially-filled templates with menus of terms to choose from in order to formulate an explanation.

5.3 Locale, setup, and participants of the study

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. It 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 same Hovercraft unit three times in three successive weeks. The teacher was neither an expert in the science content nor an expert at facilitating design-based learning. However, she was 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, all of whom volunteered to participate with permission from their guardians.

5.4 Procedure

Our intention was to carry out iterations of a design study (Barab and Squire 2004; Collins 1992; Collins et al. 2004) over the three weeks of the summer camp. We intended to integrate SHADE into Week 1 with one set of participants, and based on findings, refine its ways of promoting explanatory discourse and enact the curriculum again in Week 2 with a different set of participants. Based on the findings of second week, we would refine SHADE again and enact the curriculum a third
time with yet another set of participants in Week 3. However, due to technical difficulties in the software, we were unable to deploy SHADE during Weeks 1 and 2 of the camp. In Weeks 1 and 2, we implemented the Hovercraft unit without the SHADE software. By Week 3, SHADE was ready for deployment. In Week 3, the Hovercraft unit was implemented with SHADE integrated into it. We therefore had three sets of participants, two of which (Weeks 1 and 2) participated in the Hovercraft curriculum unit without the software and one (Week 3) which had the benefit of both the curriculum and the software. Instead of a design study, our investigation became a quasi-experiment, comparing explanatory discourse and explanatory capabilities across learners who had used the software (Week 3) and those who had not (Weeks 1 and 2). We chose to compare participants in Week 1 and Week 3 and did not include the data from Week 2. This was because, based on the analysis of Day 1 dialog of all three groups, we found that the Week 3 participants were more similar to Week 1 participants than Week 2 with respect to background knowledge and maturity levels.

Comparing the results of Weeks 1 and 3 allowed 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, and lectures.

5.5 Findings and analysis

To understand SHADE’s impact on explanatory discourse, we analyzed discourse during whole-group discussions in both Weeks 1 and 3, at the beginning of the week, several times during the week, and at the end of the week as shown in Figure 7.

Figure 7. Stages in the unit when discourse analysis was carried out
5.5.1 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 hovercrafts and science. 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. Discussions during the first morning session for both Weeks 1 and 3 were qualitatively similar, consisting of fragmented knowledge of Newton’s laws and ideas about hovering.

5.5.2 Explanatory discourse early in the week

We show samples below of written and verbal discourse from the afternoon of Day 1 of each session, when participants were working on the balloon hovercraft challenge. 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 craft to each other, the teacher reviewed experimental 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 activity during the two weeks diverged. During Week 1, participants conducted investigations in the real world, and during Week 3, participants used SHADE to conduct 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. We analyzed the written and verbal discourse of participants after their experiments with balloon hovercraft. This early written discourse comes from 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.

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 … 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 and more similar across groups 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 we do not believe that
that can be attributed to SHADE alone because the teacher had improved her understanding of the concepts by Week 3. Therefore, we do not take correctness into account in this analysis.

Our analysis of verbal discourse from that same poster session shows similar differences. We video taped and analyzed each of the presentations made during that poster session and the discussions that ensued. As can be seen in the typical samples of verbal discourse below, participants in Week 1 offered more 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, was more sophisticated in form and content and mimicked the explanations that they had articulated using SHADE.

A fuller 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.
5.5.3 Discourse at 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. Participants in Week 3 had the software available to refer to as they were working on their posters. They did not, however, choose to use it. The content of posters and verbal presentations of all groups in Weeks 1 and 3 were compared to analyze the differences in learners’ discourse towards the end of the unit. While the analysis early in the week told us about the effects with use of the software, this analysis allows us to begin to identify effects of using the software.1

To analyze the final posters and presentation, we first counted the total number of statements made by the students that warranted an explanation, including recommendations and rules of thumb. We rated each statement as a simple statement of cause and effect (Type 1), a statement with rudimentary explanation (Type 2), or a statement with a good explanation (Type 3). For example:

i. **Type 1 (simple statements)** — “...small [balloon] — has the least power, medium [balloon] — has medium power, large [balloon] — has the most power...”

ii. **Type 2 (rudimentary explanations)** — “...if the surface area increases then the hovercraft hover height decreases... [because]... the cushion pressure beneath the hovercraft will decrease....”

iii. **Type 3 (good explanations)** — “... [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 simple causal explanations without intermediate causal concepts or mere reproduction of formulas without showing any understanding of the formulas. Simple statements (Type 1) are statements without
justification of any sort. Type 3 statements are the most sophisticated, and Type 1 the least sophisticated.

Table 2 captures the findings about explanatory statements from participants in Week 1. As one can see, most statements are Type2 — rudimentary explanations (8 out of 13, 61.53 %). Most of the rest are simple statements (Type1) with no explanations associated with them.

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

<table>
<thead>
<tr>
<th>Poster and presentation theme</th>
<th>Simple statements</th>
<th>Rudimentary explanations</th>
<th>Good explanations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hull weight</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Surface area</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Motor power</td>
<td>1</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>1 fan vs. 2 fans</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Best flying saucer</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Balloon hovercraft</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Total (13)</td>
<td>4</td>
<td>8</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 3 shows the data from Week 3. In Week 3, posters and presentations had significantly fewer simple statements (Type 1) and contained an equal number of rudimentary and good explanations (Type 2 and 3). Most statements contain either rudimentary (5 out of 11, 45.45 %) or good (5 out of 11, 45.45 %) explanations.

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

<table>
<thead>
<tr>
<th>Poster and presentation theme</th>
<th>Simple statements</th>
<th>Rudimentary explanations</th>
<th>Good explanations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Difference in 1 &amp; 2 fan</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>The effect of weight</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Surface area</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Best flying saucer</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Best balloon</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>What’s a skirt?</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Hovercraft 101</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Total (11)</td>
<td>1</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

The consolidated results in Figure 8 show the overall differences between Weeks 1 and 3 with respect to the statement types. While 30% of the statements in Week 1 were simple statements (Type 1), only 9% were simple statements (Type 1) in Week 3. While only 7% of explanations in Week 1 were good explanations (Type 3), almost half (45%) in Week 3 were good explanations (Type 3).
Discussion

This study sought to explore the affordances of a mixed modeling/simulation and explanation-construction tool for enhancing learners’ explanatory discourse and explanation construction. We hypothesized that 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. Both written and verbal discourse of participants who used the explanation-construction tool in Week 3 were more sophisticated than discourse of participants in Week 1 who did not have access to the tool. 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. 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 and throughout the unit, as a direct effect of just having used the software and more indirectly after having used it several times. Third, the content of explanations from Week 3 was more elaborate and contained more intermediary causal concepts (like lift and net force) compared to explanations from Week 1.

Figure 8. Results comparing findings across Weeks 1 and 3

5.6 Discussion

This study sought to explore the affordances of a mixed modeling/simulation and explanation-construction tool for enhancing learners’ explanatory discourse and explanation construction. We hypothesized that 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. Both written and verbal discourse of participants who used the explanation-construction tool in Week 3 were more sophisticated than discourse of participants in Week 1 who did not have access to the tool. 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 and throughout the unit, as a direct effect of just having used the software and more indirectly after having used it several times. Third, the content of explanations from Week 3 was more elaborate and contained more intermediary causal concepts (like lift and net force) compared to explanations from Week 1.
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 believe we can rule out the teacher’s influence as the major contributing factor. This is because, while the teacher’s understanding of science concepts had improved by Week 3, her explanatory discourse and her methods of teaching were essentially the same in both weeks. 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 of the increased number of good 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 of 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 various 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.

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. We believe such software use has the potential to influence teachers’ discourse as well, in the same way that the software usage influences the learners. We also expect that resulting change in teacher’s discourse can be an additional influence in enculturating classroom 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 into their teaching.
6. Conclusion

Perhaps the most important lesson of the experiences presented here pertains to the role of technology in design-based science learning (DBSL). In trying to understand the challenges in implementing LBD units, we noticed some issues that one might encounter in implementing a design-based learning approach. Although DBSL has strong affordances for promoting learning of science content through design activity, realizing its benefits requires learners to make explicit connections between design activity and science concepts. Technologies such as the explanation-construction tools in SIMCARS and SHADE can be very useful in addressing this issue. Some of the features that make such technology useful in design-based contexts include (i) articulation of causal mechanisms using domain concepts and quantities, (ii) embodying simple templates to scaffold articulation, and (iii) allowing growing of explanations in an incremental fashion. Our conclusions regarding the integration and usage of explanation-construction tool are (i) by contextualizing explanation in design needs of learners, we can encourage them to want to explain, (ii) by contextualizing explanation in design exploration and investigation, learners will get direct experience at explaining their observations, and (iii) 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.

Our approach to enculturating learners into the practice of explanation construction has other advantages. We demonstrated that a software tool like SHADE makes a difference in how learners engage in collaborative learning to become better scientific explainers. Our in-depth discourse analysis suggests that the explanation-construction tool has the potential to affect collaborative knowledge construction. Often, teachers' lack of expertise in facilitating knowledge construction in design-based inquiry environments hampers development of scientific understanding among learners. But if students can use the language of a domain in well-formed explanations, there is a better chance that they can articulate their science understanding in a way others can comprehend. Such expression is essential to productive collaborative knowledge construction. Our results suggest that technologies like SIMCARS and SHADE, which model appropriate discourse, have an important role to play as mediational resources in facilitating collaborative interactions in the classroom.

Regarding promoting learning through simulation and modeling, encouraging sufficient and efficient exploration of a design space, especially those regions of the space that normally go untouched, has affordances for promoting the identification of issues that lead to deeper investigation. But promoting such exploration can pose a significant challenge during implementation because the extent of
exploration is limited not only by time and material constraints in the real world, but also by the inherent properties of the real world itself. Simulations should be a good way of addressing this issue, as simulations can adapt their time scales, facilitate quick designing, allow exploration of features of the world that cannot be changed in the real world (e.g., the value of g), include a lot of different types of materials, and provide visualizations of invisible and hard-to-see phenomena alongside the behavior of a designed artifact. Further, use of a simulation environment that parallels but extends the real world provides an infrastructure to hang an explanation-construction tool onto, and makes that tool available at times when learners might be seeking explanations. Such integration provides a natural and an authentic context for making explanations.

One of the significant insights gained from our studies is the indirect influence of simulation and modeling tools and associated explanation-construction tools and their potential for impact on learning in DBSL settings. It may be, though, that this indirect role is exactly the right one for such tools. But we recognize the need for further research on better understanding how those influences unfold in the classrooms, and how different tools interact with each other, with teachers’ practices and with students’ work. Mapping out such relationships will lead to better educational tools and more effective use of those by teachers and students.

Notes

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1. Salomon et al. (1991) discuss “effects with” and “effects of” educational software. Effects “with” are what we see participants capable of when they are using the software. Effects “of” the software are what participants are capable of as a result of having used the software earlier. Early in the week, participants created their posters based on what they had just finished doing with the software. These end-of-week data are farther removed from explicit software use and thus count as “effects of”.

References


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