Designing domain-specific blocks for diffusion: The dialogue between pedagogical principles and design decisions

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ABSTRACT

Designing computer models can be a valuable way for students to refine their understandings of scientific phenomena while creating and testing their hypotheses. Drawing on these ideas, we designed nine domain-specific blocks related to diffusion as a Scratch extension, which we called Diffusion Modeling Scratch Extension. In this paper, we describe the pedagogical principles that guided the design of the blocks and draw on the data from a pilot study with seven students to investigate how our design decisions impacted students' learning experiences.

CCS CONCEPTS

• **Applied computing**; • **Education**; • **Interactive learning environments**; • ;

KEYWORDS

scientific models, constructionism, computational thinking, domain-specific blocks

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1 INTRODUCTION

Designing computer models can be a valuable way for students to refine their understandings of scientific phenomena while creating and testing their own hypotheses. Computer models combine traditional modeling practices with computational literacy, opening new possibilities for inquiry-based learning [7, 14, 17]. Nevertheless, developing a computational model can be a demanding task for teachers and students in elementary and middle school [12, 18]. Also, most students lack previous relevant knowledge about programming and about designing a computational model. Some other difficulties include the time required for students to learn programming, the need for teachers to adjust those activities according to the students' capabilities and the teacher's levels of knowledge and experience.

In the past decades, many new environments have been designed to allow kids to create their own models using block-based programming languages (e.g., [8, 9, 13, 17]). In addition to block-based modeling, some authors (e.g., [1, 16]) designed sets of blocks for a specific discipline or phenomenon, termed "domain-specific" blocks. Drawing on these ideas, we designed nine domain-specific blocks related to diffusion as a Scratch extension, called the Diffusion Modeling Scratch Extension (DMSE). Scratch was chosen as the modeling environment for two main reasons: (a) it is a familiar environment for both students and teachers at elementary and middle school; (b) the tool is flexible, customizable, and offers the possibility of combining a wide range of blocks that already exist in the environment with the designed domain-specific blocks.

The available domain-specific blocks have an impact on the types of models students can design and on the ideas they are more likely to test while running them. Thus, the design decisions regarding the selection of the blocks have a crucial impact on students' learning experiences. This paper describes the process of designing the domain-specific blocks for diffusion based on specific pedagogical principles and draws on data from a pilot study with seven students to investigate how our design decisions impacted their learning experiences.

2 METHODS

2.1 Participants

The pilot study was conducted through individual online sessions with seven students in 5th grade (10-11 years old), four boys and three girls. The sessions were recorded and lasted approximately one hour. The first and second authors of this paper were on the call leading the activities with students.

2.2 The Diffusion Modeling Scratch Extension (DMSE) domain-specific blocks

The DMSE blocks were designed (by the authors of the paper) as a Scratch extension. We created nine domain-specific blocks related to diffusion for younger audiences who lack programming knowledge. Each block was designed to embed a set of commands that perform a specific key procedure related to the phenomenon

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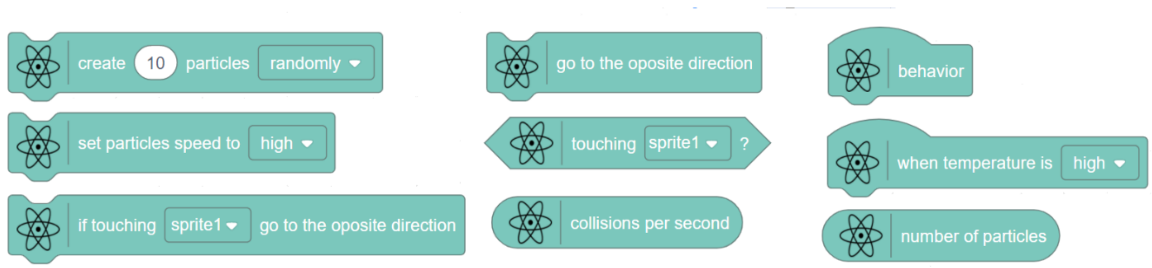

Figure 1: The domain-specific blocks designed for diffusion as a Scratch extension.

of diffusion (Figure 1). For example, students can use the blocks to express the relation between temperature and speed or test the effects of particles' collision. The blocks were designed to make it easier for students to engage in the computational scientific modeling practice and to make sense of the scientific concept of diffusion with ready-to-use pieces of code that can be combined to create specific behaviors. Without having to spend much time dealing with the complexity of the code, the idea was that students could focus their efforts on testing and refining their ideas about the mechanics of diffusion while designing a model.

2.3 Instructional sequence

The hour-long online session with individual students was based on the Bifocal modeling instructional sequence, which was tested in previous studies [2, 3, 5, 6]. The session was split into four "mini activities" followed by a short reflection interview: (1) Students watched two videos of an experiment of diffusion with food coloring in water at different temperatures. After watching the videos, students were asked to describe what they observed and create a hypothesis to explain the experimental results. (2) Students were presented with a few examples of models and were asked to explain what a scientific model is and what is its function, (3) Students were introduced to the DMSE and explored it in an open-ended way, (4) Students were asked to work on two mini-tasks, which scaffolded them gradually before they were designed the final model of diffusion to explain the experiment they observed. They started by designing a model to represent cold and hot water particles' behavior and then designed a model to represent food coloring's behavior while spreading in the water. At last, they created their final model of diffusion representing how food coloring spreads in cold and hot water.

2.4 Data sources and analysis

Data sources included seven hours of video recordings of individual sessions with the students and seven computational models of diffusion made by them. The recorded videos, which included both students' faces on the webcam and computer screen captures, were transcribed and analyzed, focusing on students' ideas regarding the concept of diffusion during the programming session. The design process of the scientific model of diffusion, including the pedagogical principles and design decisions, was documented in an authors' research journal. A Design-Based-Research [4] approach is being employed in the larger project in which this study is embedded. In this paper, we share the first iterative cycle of design, enactment in context, analysis, and redesign, from the designers' perspective.

3 RESULTS

In this section, we share the pedagogical principles that guided the development of the scientific modeling extension, the design decisions used to translate these principles into the domain-specific blocks, and finally, examples of how these design decisions impacted the way students created their models.

Two core pedagogical principles guided our design: the first was to focus on *big ideas* related to the target phenomenon of diffusion as a starting point for the design, and the second was to allow inquiry processes by offering *high ceilings*. Each of these principles led to design decisions regarding the creation of the domain-specific blocks. The design decisions resulted in different ways through which students created and interacted with the models, described in the section below.

3.1 Focus on big ideas

One of the main pedagogical principles that guided the development of the DMSE was the focus on "big ideas" regarding diffusion. "Big ideas" refer to core concepts, principles, theories, and processes that should serve as the focal point of curricula, instruction, and assessment. Big ideas reflect expert understanding and anchor the discourse, inquiries, discoveries, and arguments in a field of study, providing a basis for setting curriculum priorities that focus on the most meaningful contents [15]. The big idea about diffusion defined by us was that there is a relation between the temperature and the speed of the molecules, and that particles in a liquid are interacting with each other. In the diffusion phenomenon, this can be noticed as ink particles spread around the water at different rates depending on the water temperature. This pedagogical principle led us to make the design decisions below:

1. Select a limited number of essential blocks to explore the big ideas of the scientific phenomenon: With the focus on the big ideas of diffusion, we designed domain-specific blocks that would allow kids to explore the main scientific principles regarding the phenomenon of diffusion. For example, to explore the behavior of particles' speed and collisions, we created blocks such as "set particles' speed to high/medium/low/zero", "if touching another particle," and "go to the opposite direction". The design of the domain-specific blocks was carefully considered with the thought that students could use them to test their ideas about the phenomenon related to its "big ideas".

Table 1: The design of the domain-specific programming blocks based on Russ et al. [10] framework

Category	Description
Target Phenomenon	Ink particles diffuse from high concentration areas to low concentration areas at different rates in different temperatures
Setup Conditions.	Water and ink molecules are created pointing at random directions and move in straight lines
	Initial number of molecules: up to 300 molecules
	Initial position of the molecules: center, random, at mouse position
	Temperature: zero, low, medium, high
Entities	Water and ink molecules
Activities	Molecules can collide with other molecules and with the beaker, molecules can change their direction; molecules' speed can change depending on the temperature
Properties of Entities	Molecules' size, color and shape - these could be used to differentiate water from ink particles

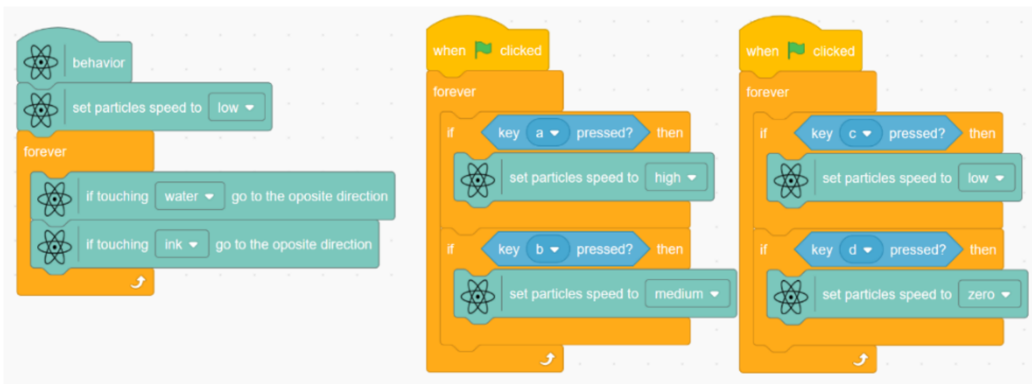

Figure 2: Rick's code to explore the phenomenon of diffusion

2. Create a "categorization" of the phenomenon to guide the selection of the blocks: Scientific inquiry focuses largely on understanding causal mechanisms that underlie natural phenomena [10, 11]. In their work, Russ et al. [10], develop a framework for discourse analysis that aids in identifying and analyzing students' mechanistic reasoning. Although their work is focused on student's discourse, we found it useful to use it as a guiding framework to identify which mechanistic reasonings we wanted learners to engage with as they used the DMSE, and how the tool could enable such reasonings. Starting with the big idea described before, we draw upon an adaptation of this framework to select the main blocks that would be presented in DMSE. While there are nine categories in original coding scheme, we selected five that seemed more suitable to frame our design (Table 1):

- (1) target phenomenon: description of the phenomenon under analysis,
- (2) setup conditions: conditions of the environment that allow the mechanism to run,
- (3) entities: elements that play roles in producing the phenomenon,
- (4) activities: the actions and interactions that occur among entities,
- (5) properties of entities: general properties of entities necessary for the mechanism to run.

Ricks' vignette: Using a limited number of blocks to describe the scientific phenomenon. Rick created a program to test out the effect of different temperatures in the outcomes observed (Figure 2). Besides using four conditions to set the particles' speed to high/medium/low/zero, he also used two blocks "if touching (particle) go to the opposite direction" to make particles change their directions when they collide with other particles (ink or water). Although he could have created the same behavior using only traditional Scratch blocks, he would probably have many more blocks and spend a considerable amount of time testing, debugging, and refining the program until it worked as desired. Thus, by using the DMSE blocks, he could engage with the big ideas behind the phenomenon in a relatively fast way.

3.2 High ceiling for inquiry

Seymour Papert is credited for saying that tools to support learning should have "high ceilings" and "low floors". The phrase is meant to suggest that such tools should allow learners to do complex and intellectually sophisticated things (high ceilings) but should also be easy to begin with (low floors). Based on the idea of high ceilings, we wanted the DMSE to allow users to test complex and diverse ideas based on exploration. Although we felt it was important to have specific blocks designed to allow learners to engage easily with the big ideas defined by us, we also wanted them to be able to represent and test their own ideas about the phenomenon, not being restricted only by the scientific ideas previously considered by us. To do this, we came up with two major design decisions:

1. Use a variety of blocks: With the focus on “high ceiling”, we decided to support kids to use our domain-specific-blocks in combination with all the other blocks, sprites, and backdrops in the Scratch environment - not hiding these features or blocks from the user, but not duplicating them either. We wanted kids to advance their models by integrating other Scratch blocks into their codes, learning to code as they learn science. In this way students could potentially test more ideas that were out of our scope, making the ceiling higher.

Anna’s vignette: **Using Scratch blocks in addition to domain-specific blocks to explore alternative ideas.** Anna was designing the model of diffusion in hot water. After creating 30 particles, she connected the speed of the particles to the temperature (When temperature is high, set particles’ speed to medium). Afterward she looked for a new block to change the color of the particles. She said: “I am trying to change the color of the particles. I think that since the color is dispersed...this will be the change in hot water”. Her hypothesis at this stage was that in hot water, when an ink particle touches the water particle it changes its color to become blue like the ink. Although we did not have a specific block for that behavior, she was able to develop her idea by integrating the existing Scratch block that allows the change of the sprite’s color with the extension blocks.

2. Create modular blocks: Another decision related to inquiry and high ceilings was the design of small pieces of code (modular blocks) that could be combined to test diverse ideas regarding diffusion. For example, instead of creating a block such as “when temperature is high change particles speed to high”, we designed two separated blocks: “when temperature is high” and “change particles speed to high”. Having those two separated blocks allows kids to explore for themselves the relation between the temperature and the speed of particles.

Anna’s vignette: Combined blocks to test alternative ideas. Anna thought that water and ink particles were not moving at the same speed: “I think that water will be a little slower than the food coloring.” So, she set different speeds for the two types of particles (ink particles with high speed and water particles with medium speed). When she ran the model and observed the results, she changed her mind: “Actually they will be the same speed because I think that they are mixing with the water”. To adjust her model, she changed the speed of both particles to high speed and tested the model while saying: “Yes... They are all the same speed and mixing together.” This example illustrates that testing the code and running the model with her hypothesis resulted in changing her initial ideas and developing another explanation for the speed of the two types of particles - something that could not be accomplished if she could only use blocks with limited behaviors.

4 CONCLUSIONS

This paper describes the first iteration of a study focused on creating domain-specific blocks for diffusion from the designers’ perspective. It shares our design experience with preliminary findings from online sessions with 5th-grade students who programmed their computational models using a Scratch extension with domain-specific blocks for diffusion. In this study, we focus on the two main pedagogical principles that guided the design of the blocks. We also present the design decisions based on those pedagogical principles and students’ learning experiences with the tool.

While designing the domain-specific blocks of diffusion, on the one hand we felt it was essential to have a specific limited number of blocks to allow kids to engage with the big ideas of the phenomenon defined by us. On the other hand, we wanted students to create scientific models that grew out of their interests and understandings, which means that the blocks needed to support inquiry and a wide range of ideas. The domain-specific blocks available for students to create their models have a crucial impact on the types of models they will make. Consequently, the available blocks will impact their understandings and the hypotheses they are more likely to test regarding the scientific phenomenon.

In the future, we expect to keep refining the blocks based on new pilot studies with students, and to explore their learning trajectories more deeply to better understand the affordances and limitations of using the DMSE to engage in mechanistic reasonings about diffusion.

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