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Never far from shore: productive patterns in physics students' use of the digital learning environment *Algodoo*

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Abstract

In this paper, we present three types of activity that we have observed during students' free exploration of a software called *Algodoo*, which allows students to explore a range of physics phenomena within the same digital learning environment. We discuss how, by responding to any of the three activity types we identify in the students' use of *Algodoo*, physics teachers can springboard into a range of relevant physics discussions while supporting and valuing student agency and divergent thinking. Thus, while one might not expect students' undirected use of a digital tool such as *Algodoo* to be particularly worthwhile for the physics classroom, we highlight how students are never 'far from the shore' of a productive physics discussion.

Keywords: *Algodoo*, grounded theory, digital learning environment, exploration, testing, engineering, creativity

1. Introduction

With regards to digital learning environments in physics education, on one hand there are software that focus on specific phenomena, e.g. PhET simulations [1], Physlets [2], QuVis animations [3], and, on the other hand, software that function more as creative arenas within which many phenomena can be explored, e.g. *Algodoo* [4], Interactive Physics [5], and Fizika [6]. We refer to the former category of phenomena-specific digital learning environments as 'constrained' and the latter as 'less-constrained' [7], owing to the degree to which those environments are designed to 'productively constrain' [8] students' behavior (see also [9–11]). While both constrained and less-constrained digital learning environments have unique affordances for supporting physics students' learning, constrained software has received significantly more attention from developers and physics education researchers in recent decades. In this paper, we present our findings for some of the ways in which one less-constrained digital learning environment—specifically, *Algodoo*—can be productive for the physics classroom, specifically when students are allowed to freely explore within the software for themselves.

Given the relative open-endedness of less-constrained software such as *Algodoo*, a physics teacher who includes this type of digital learning environment in their repertoire of curricular materials can choose to implement the software in a range of ways. At one extreme, a teacher can use *Algodoo* as a means for students to engage with specific physics content in directed tasks. In this approach, students can use *Algodoo* to explore a range of physics topics, from projectile motion [12] to Kepler's laws [13], kinetic gas theory [14], and the refraction of light [15], all within the same digital learning environment. This topic-specific use of a less-constrained software more closely resembles the productively controlled approach behind many constrained physics learning software mentioned above[3].

At the opposite extreme, a physics teacher can choose to take a more student-directed approach: that is, a teacher can refrain from selecting specific topics, allowing students to explore the software for themselves and responding to the students' exploration at opportune points. Such a student-directed approach may intuitively seem too unfocused to be worthwhile for the teaching and learning of physics. However, we have found that students' self-directed exploration within the less-constrained software, *Algodoo*, has several unique, if unanticipated, affordances for physics education [7].

[3] While there is a resemblance between a topically-focused use of less-constrained software and the typical use of constrained software, it should be pointed out that in the case of the former, many of the constraints are imposed by the teacher rather than through the imposed limitations of the software itself.

In this paper, we describe three types of activities identified while observing students' self-directed use of *Algodoo* and explain how each activity type has the potential to be productively leveraged by a physics teacher. Among other things, we show that, by allowing students to creatively explore within tool-rich physics environments such as *Algodoo*, physics teachers can springboard into a range of relevant discussions while supporting and valuing the agency and divergent thinking of students.

2. Three types of student activity in *Algodoo*

The three activity types we present in this paper were identified based on the analysis of video recordings of seven pairs of university physics students as they used *Algodoo* for the first time[4]. Through the use of a grounded theory method [16], the video recordings were iteratively viewed, transcripts were generated, student behavior was coded in successively larger chunks, and, ultimately, three categories of activity were identified. Below, we present each of these activity types, along with their potential relevance for the teaching and learning of physics.

2.1. Activity type 1: exploration of the software fundamentals

During the first activity type, which we call *exploration of the software fundamentals*, students investigate the tools and functions of *Algodoo*. This activity type is characterized by students familiarizing themselves with *Algodoo*'s buttons, toolbars, and drop-down menus (see figure 1) in order to develop a sense for the basics of how the software is operated. Students' *exploration of the software fundamentals* tends to be (outwardly) chaotic, exemplified by the students shifting their focus between the many features housed in *Algodoo*. Especially when students are new users of *Algodoo*, this activity type is the behavior which physics teachers

[4] The activity types presented in this paper were originally identified in Prytz's master's thesis [28]. For those interested, a full discussion of the data and methodology can be found there.

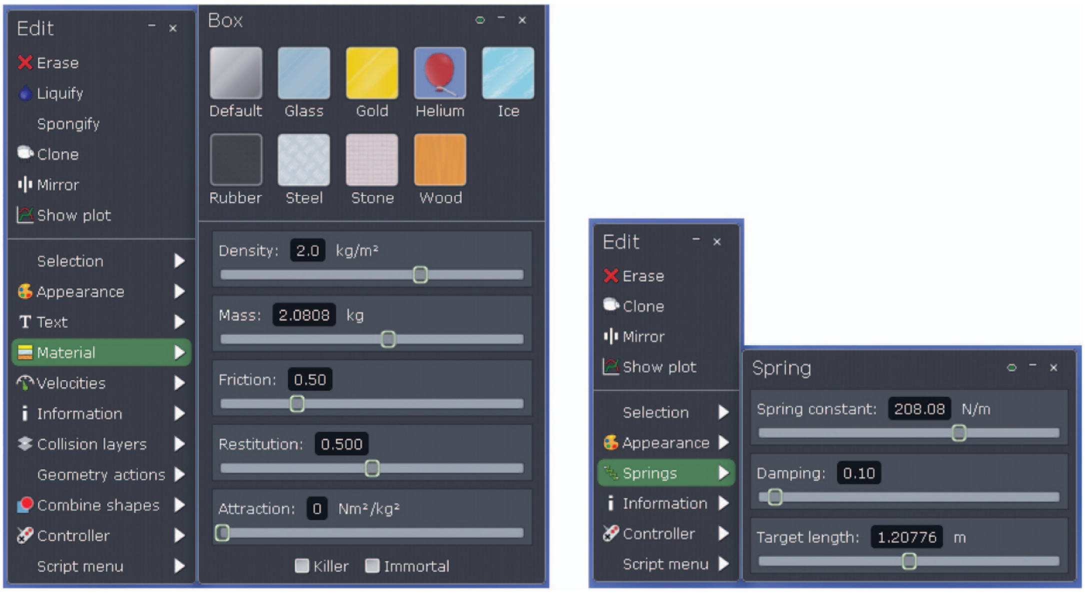

Figure 1. Two examples of the Edit drop-down menus that students tend to familiarize themselves with in *Algodoo* during the first activity type, *exploration of the software fundamentals*. On the left, the Edit menu is shown open to the Material submenu, where students can vary the density, mass, coefficient of friction, etc for the object(s) selected. On the right, the Edit menu is shown open to the Springs submenu, where students can vary the spring constant, viscous damping parameter, and target length of the selected spring(s).

should expect to see chronologically first. Additionally, due to the high number of features made available in *Algodoo*, students frequently return to this activity type throughout their exploration as they discover new functionalities of the software.

Students' *exploration of the software fundamentals* can be productive for the physics teacher insofar as students naturally uncover new physics parameters. While students 'poke around' in the *Algodoo* software, they interact with the buttons and sliders corresponding to various parameters that are relevant to the discipline of physics (e.g. restitution, damping, speed/velocity, gravity, kinetic energy, and so on). Depending on the students' familiarity with the formalisms of physics, the parameters encountered in *Algodoo* will be more or less recognizable to the students. A physics teacher can notice which parameters seem to be less-recognized by students and encourage those students to further investigate those parameters unfamiliar to them. For example, elsewhere we have analyzed how two students came across the slider labelled 'Damping' within the editing menu for springs (figure 1, right) and were guided by researchers to make sense of the behavior of damped/undamped springs [7].

2.2. *Activity type 2: testing and contrasting*

In the second activity type, which we call *testing and contrasting*, students explore how well the physics engine of *Algodoo* matches the real world. Students tend to construct classic physics scenarios within the software to ensure that the software behaves as it should (e.g. dropping two objects from the same height to 'demonstrate' the acceleration due to gravity) or they create simple tests to determine if the software allows for certain complexities of physics interactions (e.g. dropping a square onto a thin rectangle given the material preset of 'glass' to see if glass objects shatter in *Algodoo*[5], figure 2). In general, we have found that students engage in *testing and*

[5] *Algodoo* allows the user to assign material presets such as glass, wood, steel, etc, to objects, which correspond to certain configurations of the objects' density, friction properties, restitution, and refractive index.

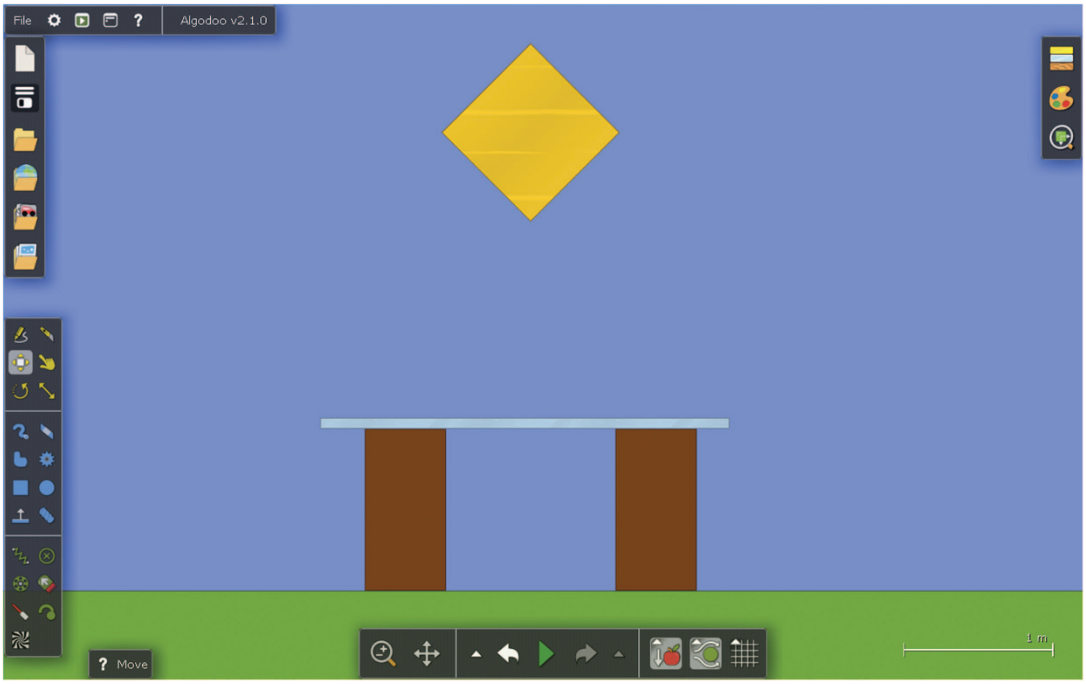

Figure 2. A screenshot of an observed *testing and contrasting* activity in *Algodoo*—recreated by the authors for clarity in this publication—where two students tried to shatter a thin rectangle made with the 'glass' material preset (shown in light blue laying horizontally on top of two support rectangles) with another, massive object (the gold square at the top of the screen). After running the simulation, the students concluded that *Algodoo* does not allow the breaking of objects.

contrasting to check 'how far' they can go within the software.

For the physics teacher, *testing and contrasting* activities can be productive in that they can be leveraged to highlight the role of modeling in physics [17, 18]. For example, in the case shown in figure 2 involving the 'glass' rectangle, a physics teacher could interject to ask students about whether the *Algodoo* software is still a valid environment for exploring physics phenomena. Previous research findings have highlighted that software such as *Algodoo* have the potential to be a resource for entry-level physics modeling [4, 19], where the intuitive interface allows students to examine dynamic models of physical phenomena without a prerequisite proficiency in programming. Beyond supporting discussions of physics modeling, students' *testing and contrasting* activities can serve as the backdrop for introductory discussions around the use of computer simulations in modern science [20].

2.3. Activity type 3: engineering

In the third activity type, which we refer to as *engineering*, students tend to prototype machines/setups in the pursuit of self-determined goals within *Algodoo*. For example, some students constructed a simple car and, after getting their car rolling, created obstacles such as a small hill for the car to traverse (figure 3). In doing so, these students were motivated to explore the role of friction, torque, etc, in the context of a car climbing a hill. In many cases, the students' impetus to construct machines comes during their noticing a specific feature of *Algodoo* in their *exploration of the software fundamentals* (activity type 1). After finding *Algodoo*'s 'thruster' tool, for instance, students might quickly transition into building a rocket. We have found a salient feature of *engineering* activities is students' modification of their machines in pursuit of their self-determined goal. In this way, students' *engineering* activities seem

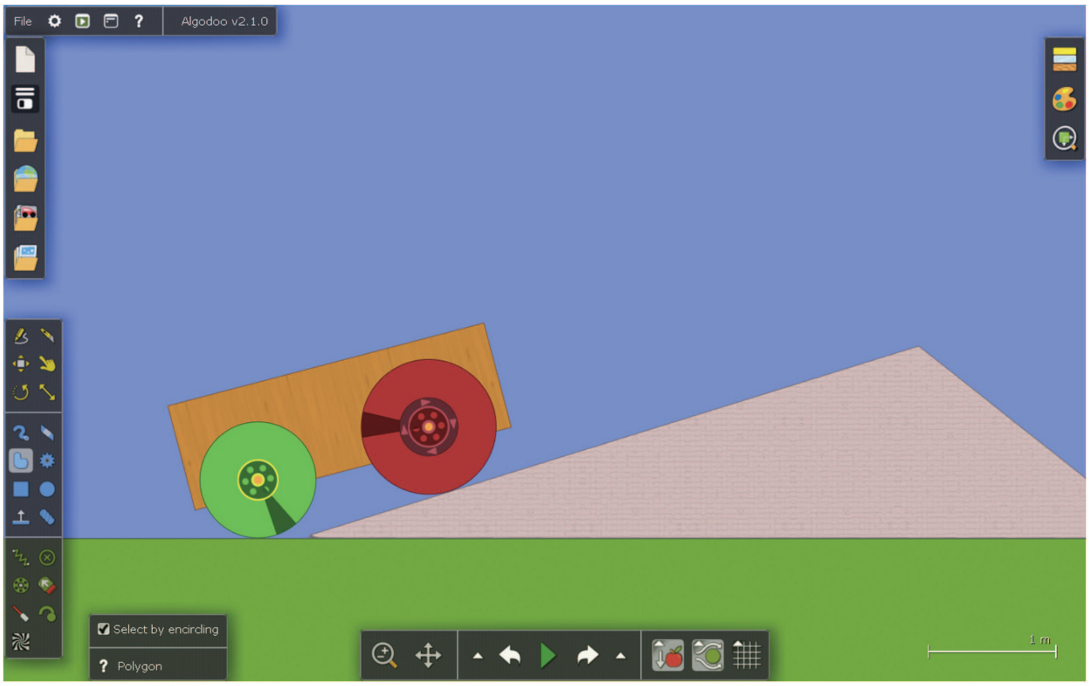

Figure 3. A screenshot of the kind of machine typically created by students in *Algodoo*—again, recreated by the authors for this publication—as they engage in the third activity type, *engineering*. A simple car consisting of a rectangular 'body' and two circular 'wheels' (fitted with motor-driven axels) drives up an angular obstacle also created by the students. In achieving the goal of driving their simple car up and over this obstacle, students engage with the coefficient of friction of the wheels/ramp and the torques applied to the motor-driven axels, among other things.

to involve iterative loops wherein they design, test, and challenge various prototypes.

Students' *engineering* activities are potentially useful for the physics classroom in that they often entail students working in ways that resemble pedagogically-sought-after scientific practices [21]. More precisely, during the prototyping typical in *engineering* activities, students often design tests for achieving self-determined goals, evaluate the outcome of their tests, and iteratively revise their constructions to accommodate those outcomes. This sequence of reasoning may constitute what Gregorcic *et al* [22] describe as the 'seed[s] of scientific practices'—or perhaps in our case, the seeds of engineering practices. A teacher can take advantage of students' *engineering* tasks by prompting students to reflect on their prototyping process, which may subsequently be turned into a discussion of the characteristics of scientific and engineering practices more broadly [23, 24]. Alternatively, since *Algodoo* allows for the 'zooming in on' and the 'unpacking of' the various parts within a construction, teachers can utilize students' machines/setups as the focus for further inquiry. For example, when a pair of students engineered a way to lodge an arrow into a 'sponge' in *Algodoo*, researchers were able to utilize the students' success in meeting their goal as the basis for a discussion on how non-rigid bodies are modeled in the software [7].

3. Summary of implications for teaching

When allowed to explore software such as *Algodoo* in a self-directed manner, students are likely to engage in some combination of the three activity types detailed above, each of which can be potentially productive for the teaching and learning of physics in their own way (table 1). A teacher who allows students to engage in this kind of activity can choose to build upon students' exploration [25] during any of the three activity types

Table 1. A summary of the three activity types we identified in students' use of *Algodoo* without a specific prompt.

Activity type	Explanation	Productiveness for the physics classroom
Exploration of the software fundamentals	Students develop a sense for the tools and functions of the software environment	Students can naturally uncover relevant physics parameters
Testing and contrasting	Students explore how the software's physics engine compares with the real world	Can serve as a backdrop for discussions about physics modeling and the use of computers in science
Engineering	Students create machines/setups and pursue self-determined goals	Students' engagement in science- and engineering-like practices may be unpacked for further discussion; students' creations can be taken up as the focus for further inquiry

in order to guide the students' attention to the type of discussion that the teacher wants. Building from the first activity type, students' *exploration of the software fundamentals*, a teacher can encourage students to explore the meaning of various parameters as they are uncovered in the software interface. With students' *testing and contrasting*, the second activity type, a teacher can springboard into entry-level discussions on the role of modeling in physics and the function of computer modeling in scientific inquiry. Finally, from the third activity type, students' *engineering*, teachers can take on students' creations for discussions around scientific practices and/or as inspiration for more topic-specific discussions of particular phenomena. Among other things, allowing students to explore less-constrained physics software such as *Algodoo* in a self-directed manner can signal to those students that their creativity, divergent thinking, and, ultimately, *agency* [26] is valuable to the process of learning—and doing—physics.

3.1. Additional considerations for teachers encouraging students to explore Algodoo

While we have so far used this paper to highlight ways in which students' use *Algodoo* can be productive for the physics classroom, it is worth mentioning some potential challenges physics teachers might face when encouraging an entire class of students to 'freely explore' less-constrained digital learning environments. First, in larger classes it may be difficult to manage multiple groups of students that may be headed in divergent, often unrelated, directions. In our experience, we have found that a single teacher, who is familiar with the software, can manage classes on the scale of 20–30 students (in groups of 2–3). Alternatively, teachers can encourage students to explore *Algodoo* as homework or within a lab-style setting where student-teacher ratios tend to be smaller.

A second challenge that physics teachers might face when implementing *Algodoo* in their classroom is that allowing students to 'mess about' in such digital learning environments simply takes more time to reach certain learning goals when compared to more pointed discussions/lectures of desired topics. Our recommendation regarding this concern is that teachers consider incorporating student-directed use of *Algodoo* into their toolbox of active learning approaches and, ultimately, decide for themselves what balance to strike in the pacing of content goals.

Finally, since every student group will, by design of such a teaching approach, end up engaging in different activities and pursing their own goals, a third challenge teachers might face when incorporating *Algodoo* in their classrooms is that there is a loss of a single shared experience for students. In response to this last challenge, we recommend that teachers intermittently pull the full class together for a discussion around a particular group's work. This may help all of the students reflect on the nature of their own work and may encourage them to generalize some of their productive ideas across the various contexts that appear in other students' work [27].

4. Conclusion

Regardless of whether students are 'poking around' in *Algodoo*'s menus, checking the boundaries of the software's physics engine, or creating machines to meet their own goals, physics teachers can be assured that students' self-directed exploration of less-constrained digital learning environments is a near neighbor of a worthwhile physics discussion. Thus, as long as the interested physics teacher is willing to build upon the divergent activity of students engaging with less-constrained digital learning environments such as *Algodoo*, their students will likely never be 'far from the shore' of productive physics discussions.

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