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Affordances and constraints of the Dragonbox School teaching material

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The aim of this paper is to analyze the affordances and constraints of the way dynamic representations are used in the digital learning lab 'The set line' from the Dragonbox School teaching material. The learning lab is designed for second graders. The starting point of our analysis is the task 18 + 6. Our analysis shows that 'The set line' offers affordances for the users' learning of addition and other aspects of the number concept because the regrouping involved in the addition of 18 and 6 is explicitly displayed by the dynamic representations in the learning lab. 'The set line' may also cause constraints for students' opportunities to learn the inherent mathematical concepts and relations because several operations are carried out automatically by the learning lab.

Keywords: Addition, affordances, constraints, digital tool, dynamic representation.

Introduction

Digital tools may provide dynamic representations (Ainsworth & VanLabeke, 2004; Günster, 2019) which offer visualizations of mathematical concepts and relations. The digital tool under scrutiny here, is the Dragonbox School teaching material. When users, i.e., second grade students, interact with this tool, the dynamic representations are changed according to the input of the users. Such changes may make essential features of the mathematical structures more apparent, and this may facilitate understanding of the mathematical concepts and relations involved. If the students had been working with static representations, like concrete materials, these structures would in many cases not have been made apparent in the same way. For example, students may separate a digital rod representing the number 7 into a two rod and a five rod. This process demonstrates a decomposition of the number 7 not facilitated by physical rods in the same manner.

The reason for choosing the Dragonbox School teaching material, from now on called 'Dragonbox School', is that it contains digital learning labs which facilitate open-ended explorations and visualizations of mathematical concepts and relations using dynamic representations. These learning labs are designed in a way that enables the students to use them with little or no support from the teacher. The students are invited to explore on their own how the learning labs work and use these labs to explore mathematical concepts and relations. This approach to designing mathematical teaching material is rather novel. Because Dragonbox School was launched in 2018, very little research is carried out concerning this teaching material. Therefore, it is interesting to know more about the affordances offered by the learning labs, and the constraints they may cause in the learning process.

Dragonbox School is made by the company Kahoot Dragonbox AS and is used in Norway, Finland, and France. It consists of digital resources, textbooks, and concrete manipulatives for 1st to 4th grade. The digital resources consist of learning labs and quizzes developed for use on tablets or laptops with touchscreens. The quizzes are learning labs combined with mathematical tasks. The textbooks mainly consist of different types of tasks the students may work with. The concrete manipulatives, called *nooms*, are a development of the Cuisenaire rods (March, 1977). These concrete manipulatives also appear digitally in the learning labs and quizzes. Each of these manipulatives corresponds to a natural number between 1 and 10, see Figure 1.

Figure 1: The nooms in Dragonbox School

Dragonbox School is supposed to be used according to 'The Dragonbox method'. In the teacher manual (Dragonbox Kahoot, 2021), every lesson is structured according to this method. Each lesson consists of four phases: 1) exploration; 2) discussion; 3) practice; and 4) recapitulation. In the exploration phase, the students explore a digital learning lab individually, with a fellow student, or with the teacher in a whole class discussion. In the discussion phase, the students are given time to think, discuss with a learning partner, and share their reasoning with the teacher and the rest of the class. In the practice phase, it is recommended that the students start to work with the quizzes and then solve tasks in the textbook. In the recapitulation phase, the teacher facilitates a whole class discussion about the learning goal of the lesson and how the activities of the students are linked to this goal.

Theoretical framework

The work of Brissiaud (2016) has been central in the development of Dragonbox School (Uggerud, 2021). Brissiaud argues that solid understanding of a number means having access to its decompositions. This claim is supported by other researchers (Anghileri, 2000; Ma, 2010). With a developed conceptualization of the cardinality of number, e.g., the number eight, a student can easily think of different decompositions of this number: 8 = 7 + 1, 8 = 5 + 3, 8 = 4 + 4, etc. The idea of decomposition and composition led to the construction of the nooms, which play important roles in Dragonbox School. Using a tablet, one can split (decompose) one noom into two smaller nooms by 'slicing' it with the finger, and one can join two nooms (compose) by moving one on the top of the other. Then the bottom noom will 'eat' the upper noom and grow accordingly.

Duval's (2006) theory of representations is central in our analysis of Dragonbox School. He defined the concept of representation as "something that stands for something else" (p. 103). He stressed that "the ability to change from one representation to another is very often the critical threshold for progress in learning and for problem solving" (Duval, 2006, p. 107). Dragonbox School offers several activities where students have to change from one representation to another. The concepts of treatments and conversions are core elements in Duval's theory of representations. Treatments are "transformations of representations that happen within the same register" (Duval, 2006, p. 111), e.g., decomposing a 6-noom into a 2-noom and a 4-noom and composing a 5-noom by concatenating a 3-noom and a 2-noom. Conversions are "transformations of representations that consist of changing a register without changing the objects being denoted" (Duval, 2006, p. 112), e.g., transforming the number 6 into the 6-noom. When the students manipulate the dynamic representations in the learning labs and quizzes of Dragonbox School, both conversions and treatments are carried out. Skemp's (1976) terminology of 'relational understanding' and 'instrumental understanding' of mathematics will also play an important role in our analysis of Dragonbox School. 'Relational understanding' refers to "knowing both what to do and why" (Skemp, 1976, p. 20), and 'instrumental understanding' refers to "rules without reason" (Skemp, 1976, p. 20). Relational understanding should, according to Skemp, be the goal of mathematical learning.

Affordances and constraints are two terms often used in mathematics education research in evaluation of teaching materials and learning activities (e.g., Carlsen et al., 2016; David & Watson, 2008). Gibson (1979) launched these terms. He defines *affordances* as relationships between the environment and the animal, in our case the digital environment of Dragonbox School and students. Gibson argues that these affordances exist independently of the user, but the user has to perceive these in order for them to be realized. Additionally, Norman (1988) emphasizes that affordances are linked to cultural conventions. We thus argue that in a digital environment, affordances denote action possibilities offered by a digital tool with respect to the capabilities of the user of that tool. The goals of actions and interactions with a digital tool, the user's mathematical experience, and the mathematics classroom culture fundamentally informs the user's perception of affordances. *Constraints* is a term that denotes factors delimiting the user's actions and interactions with the environment. Such delimitations may support the user to focus at intended mathematical content.

In our study, inspired by Gibson (1979) and Norman (1988), we draw on these constructs and situate them to fit our purpose of analyzing Dragonbox School. Therefore, we use affordances to denote possibilities offered for the user's actions and interactions with a digital tool that, if perceived, may nurture the development of relational understanding. We use constraints, despite the term's denotations as to also support users' attention, to denote the inherently emerging restrictions for the user's actions and interactions with a digital tool that may delimit opportunities for developing relational understanding.

Based on these ideas and considerations, we will analyze a specific learning lab called 'The set line', which will be described below. We have thus formulated the following research question:

> Which affordances and constraints can be identified in 'The set line' with respect to how it facilitates treatments and conversions in addition of single- and two-digit numbers?

Presentation and analysis of the learning lab 'The set line'

We immersed ourselves with the Dragonbox School teaching material and familiarized ourselves with its various resources. Particularly, we became interested in the learning labs due to their visualizations of natural numbers. In this study we analyze a learning lab called 'The set line' because it explicitly displays both treatments and conversions (cf. Duval, 2006). We inspected actions made possible by this learning lab, and further analyzed these actions' affordances and constraints with respect to the task "Compute 18 + 6". We have chosen this task because it involves the decomposition of 6 into 2 and 4. Such decompositions are a central theme both in the Norwegian curriculum (Utdanningsdirektoratet, 2020) and in Dragonbox School. Moreover, decompositions are fundamental to understanding addition and numbers in general (Brissiaud, 2016).

The insertion of 18 into the two first containers[1]

To carry out the calculation 18 + 6, the student must start by producing the number 18. To do this, the student has to press the grey area on the tube in the upper left corner of the tablet surface, causing three empty fields to appear (see Figure 2). Then, in the last two of these, the student must write 18 using a finger on the tablet surface. Then a 10-noom (black) and an 8-noom (pink) emerge from the tube displayed on top of each other (to the left in Figure 2). Using the terminology of Duval (2006), the digital tool conducts a hidden treatment of the number 18 into the numbers 10 and 8. Then, a conversion of the numbers 10 and 8 into the 10-noom and 8-noom is carried out and visualized. Therefore, this treatment-conversion may nurture the development of relational understanding of the number 18. This treatment-conversion may thus constitute an affordance in the student's learning process.

To proceed with the calculation, the student has to press the 10-noom and the 8-noom using a finger. When this is done, a funnel appears at the left side of the first container, see Figure 2:

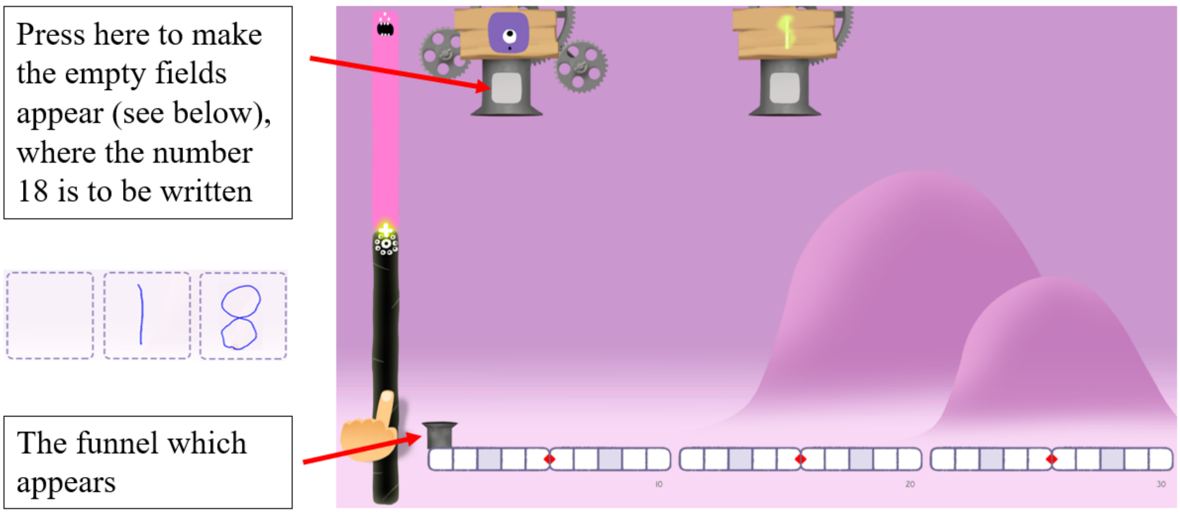

Figure 2: The funnel appears when the 10-noom and 8-noom are pressed. Text boxes and arrows are added by the authors

[1] By "container" we mean one tube with space for ten 1-nooms, as displayed at the bottom of the tool screen in Figure 2.

The funnel is automatically positioned at the correct place, namely at the first vacant cell in the first container. This informs the student about what to do next, that is, to insert the 10-noom and the 8-noom into the first container through the funnel. When the 10-noom and the 8-noom are inserted into the funnel, ten 1-nooms are fed one by one into the container, and a ‘thumping’ sound is heard as each 1-noom is fed into the container, see Figure 3. Then the feeding-process stops, and the remaining 8-noom is automatically moved to the second container. Using the terminology of Duval (2006), a treatment from one 10-noom to ten 1-nooms is carried out and explicitly displayed by the learning lab. This may nurture the development of relational understanding of this treatment and may thus constitute an affordance in the student’s learning process.

When the remaining 8-noom is moved to the second container, a funnel automatically appears at the first empty cell in the second container, see Figure 3. In this way the student is informed about what to do next, namely, to insert the 8-noom into the first vacant cell in the second container. When pressing the appeared funnel, the 8-noom is fed into this container in a similar way as the 10-noom was fed into the first container. Nevertheless, the two automatic actions may constitute a constraint in the student’s learning process. The only thing the student needs to do, is to insert the 10-noom and the 8-noom into the funnels. This may be mastered without relational understanding of the composition of the number 18. These two automatic actions may thus delimit the development of relational understanding.

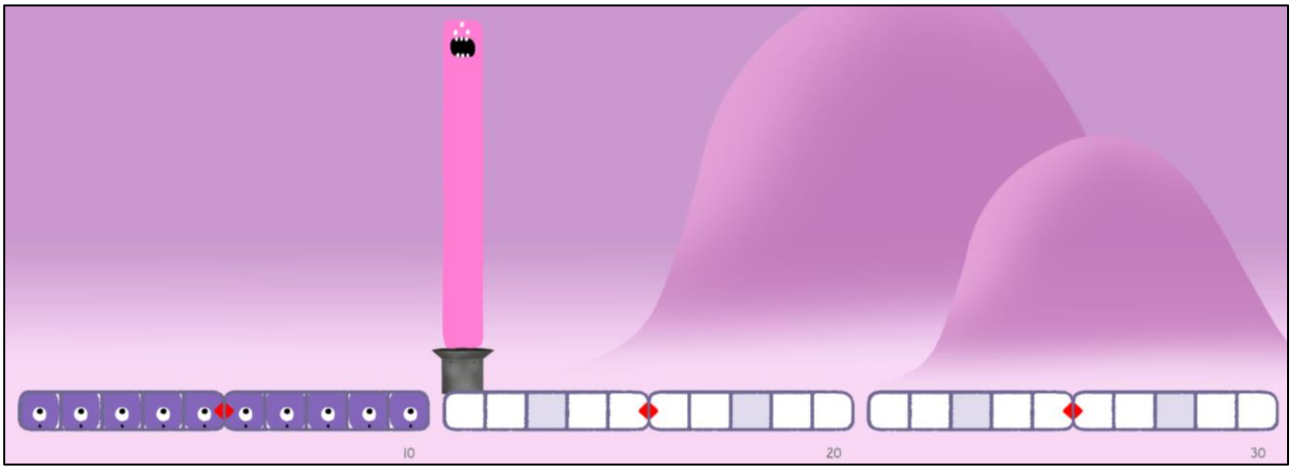

Figure 3: The remaining 8-noom is moved to the second container and a funnel appears

The insertion of 6 into the second and the third containers

To proceed with the calculation 18 + 6, the student needs to press the grey area on the tube once more, as when producing the number 18, and write 6 in the empty fields that appear to produce a 6-noom (orange). To complete the calculation, the 6-noom has to be decomposed into a 2-noom and a 4-noom. This decomposition can be carried out either automatically or manually. We begin with explaining how this can be done automatically. First, the student has to press the 6-noom. When this is done, a funnel with an addition sign automatically appears at the first vacant cell in the second container, see Figure 4.

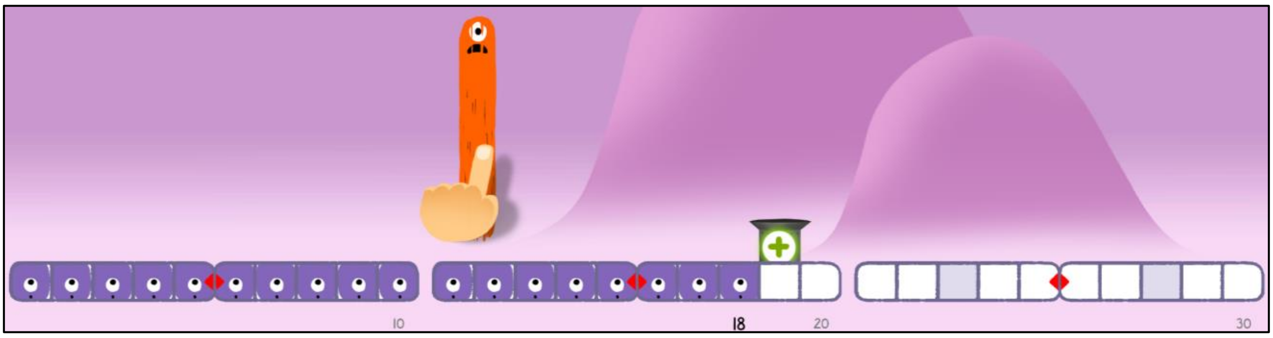

Figure 4: A funnel appears in the first vacant cell in the second container

The positioning of this funnel informs the student to insert the 6-noom into the funnel at the correct place, namely, the first vacant cell in the second container. This is indicating that the second container should be filled first. When the student moves the 6-noom to the funnel and presses the funnel, the 6-noom is starting to be fed into the container, but the process stops after the two first 1-nooms are fed into the container. Then the second container is full, and the remaining 4-noom (green) and the funnel are automatically moved to the first vacant cell in the third container, see Figure 5. Then the student has to press this funnel to insert the 4-noom into the third container.

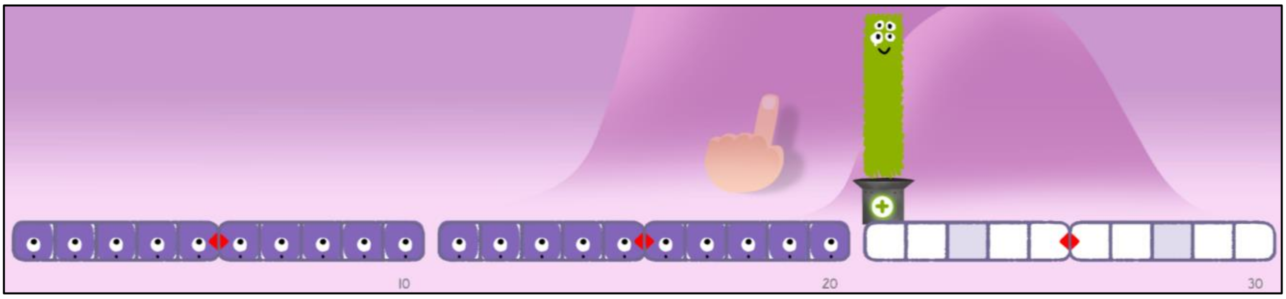

Figure 5: A funnel appears in the first vacant cell in the third container

In this way the student may notice the decomposition of the 6-noom into one 2-noom and one 4-noom. According to a Duvalian (2006) stance, this corresponds to a treatment from one 6-noom to one 2-noom and one 4-noom. This treatment is explicitly displayed, and this may nurture the development of relational understanding of the decomposition of 6 into 2 and 4. This treatment may thus constitute an affordance in the student's learning process. However, the automatic appearances of the two funnels at the correct places, may constitute constraints in the student's learning process. The only thing the student needs to do to proceed with the calculation is to feed the nooms into the funnels. This may be mastered without relational understanding of the decomposition of 6 into 2 and 4. The automatic appearances of the two funnels at the correct places may thus delimit the development of relational understanding.

When the student presses the funnel to insert the 4-noom into the third container, the number 24 automatically appears below the last 1-noom in the third container, see Figure 6. The appearance of this number corresponds to a hidden conversion from twenty-four 1-nooms into twenty-four 1s, which through a treatment become the number 24. This visualizes that the number 24 consists of two containers filled with ten 1-nooms each, and a container filled with four 1-nooms. This visualization may nurture the development of relational understanding of the number 24. Thus, the automatic conversion-treatment from twenty-four 1-nooms to the number 24, may constitute an affordance in the student's learning process.

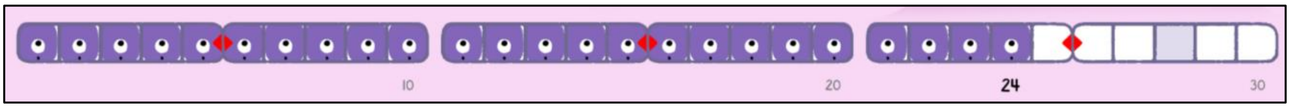

Figure 6: The conversion from twenty-four 1-nooms to the number 24

The decomposition of the 6-noom into the 2-noom and the 4-noom can also be carried out manually by 'slicing' the 6-noom with the finger. If this 'slicing' is done correctly, that is a bit above or below the middle of the 6-noom, the 6-noom will be decomposed into a 2-noom and a 4-noom. Then the 2-noom can be inserted in the second container, and the 4-noom in the third container. This manual decomposition may constitute an affordance in the students' learning process because it may nurture the development of relational understanding of the decomposition of 6 into 2 and 4.

Discussion and conclusion

Our analyses show that 'The set line' may constitute both affordances and constraints with respect to students' learning process. Firstly, we will address the affordances. These relate to how the learning lab may nurture the development of relational understanding by utilizing the dynamic potential of visualizing the addition process. With respect to conversions (Duval, 2006), the learning lab for instance transforms the numbers 10 and 8 into a 10-noom and an 8-noom. With respect to treatments (Duval, 2006), the learning lab visualizes transformations within the noom-setting: how the 10-noom is made up of ten 1-nooms, and how the 6-noom strategically can be decomposed into a 2-noom and a 4-noom in order to utilize the grouping of tens in our number system. Moreover, the learning lab visualizes how addition is executed by adding the second addend from where the first addend ends at the set line and then reading off the final endpoint. Thus, we claim that 'The set line' offers substantial affordances when it comes to visualizing basic number concepts and relations.

In our analyses, we have described operations that are automatically carried out by 'The set line'. These operations may facilitate the learning process because the students are guided regarding what to do next. Therefore, it is likely that the students may be able to operate this learning lab with little or no support from the teacher. This is an important point because one purpose of the learning labs is to enable users to explore mathematical concepts and relations on their own. However, the operations that are carried out automatically, may constrain students that would benefit from conducting these operations themselves. Moreover, these automatic operations may enable students to solve the tasks at hand without having relationally understood these operations. The students may write the numbers provided by the tasks without reflecting on the meaning of the numbers, and they may move the available noom(s) to the nearby funnel without reflecting on why this should be done and without paying attention to the ongoing visualizations. Furthermore, if the decomposition of the 6-noom into the 2-noom and 4-noom is carried out automatically, the students may be constrained from deciding on how the decomposition of the second addend is to be carried out. The operations that are automatically carried out may thus deprive the students of opportunities for learning.

We want to point out that if 'The set line' is used according to the Dragonbox method, the impact of the constraints we have described, may be significantly reduced. This method strongly recommends teachers to nurture student reasoning concerning the inherent mathematical content of the learning labs and quizzes. The Dragonbox method is explained in the teacher manual, and it is also taught in courses for the teachers who use Dragonbox School. Nevertheless, to inform and teach about the Dragonbox method do not necessarily prevent students from using the learning labs and quizzes without achieving relational understanding.

Our conclusion is that ‘The set line’ may offer both affordances and constraints in the users’ learning process. The students’ outcome is to a great extent dependent on teachers facilitating student reasoning about the dynamic representations and the inherent compositions and decompositions (cf. Brissiaud, 2016) of the learning lab. Further, empirical research is needed that investigate whether the identified affordances and constraints are experienced as such by students who engage with the learning labs.

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