Towards improving teaching and learning of algorithmics by means of resources design: a case of primary school education in France

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This article is devoted to the problem of design of resources in algorithmics for teachers of primary school in France. We investigate what elements should contain such resource in order to support the learning intended by authors of the resource, during its implementation by teachers who works in different contexts. To contribute to this question, we study the design principles of a particular resource in algorithmics. We follow this resource from the moment of its creation by a researcher and an experienced teacher to its appropriation and usage by three ordinary teachers. Paper describes how the results of analysis of lessons observations, interviews and collective discussions with teachers pointed to missing elements of the resource and, hence, contributed in its enhancement. The results of the study aim to bring some elements for improving the teaching of algorithmics by means of resources and, as a result, to support the learning of the involved concepts.

Keywords: Algorithms, resources, primary education, teacher.

Introduction

Algorithmics (Lagrange, 2014) is more and more present in school education of different countries. In France, the elements of algorithmics and programming were introduced in primary and middle school curricula in 2016. In our previous work, we analysed the didactical transposition (Chevallard, 1985) of the main concepts of algorithmics in French curriculum of cycle 4 (grades 7-9) and showed its partial nature with a focus on the effectiveness aspect of algorithm and on the usage of algorithm as a tool (Modeste & Rafalska, 2017). The following analysis of didactical transposition of concepts of algorithmics in French curriculum resources for cycle 3 (grades 4-6) showed the existence of the same orientations.

In French curriculum of cycle 3, content related to algorithmics and programming is included in the chapters “Mathematics” and “Sciences and technologies”. For example, in the theme “Space and geometry”, it is suggested to make an introduction to programming by using activities of spotting and displacement (coding the movement of a robot or a character on the screen) as well as geometrical activities (construction of simple figures and figures composed of simple figures). In the theme “Materials and technical objects”, it is mentioned that the notion “algorithm” could be discovered by pupils using “visual applications”. Curriculum guidelines for teachers (published by Ministry of education of France) highlight the importance of development of pupils’ knowledge of “the basic principles of algorithmics and software design” and indicate that the usage of unplugged activities could be the first step for introducing pupils to the notion of algorithm. However, the concept of algorithm is not defined and it seems that the main learning objectives of such activities is the development of rigor. Most of given examples present algorithm through programming tasks, using robots or different environments (like Scratch, Scratch JR, Géotortue, etc.). Analysed textbooks for cycle 3 (in particular, collections Nathan and iParcours for grade 5, Delta for grade 6)

follow the recommendations of the curriculum and teacher's guides, and propose mostly programming tasks (usually about drawing figures on the screen) and games in Scratch without distinguishing the notions of algorithm and program. Such focus on programming leaves out other important aspects of algorithm, for example, the role of algorithms for problem solving.

Interviews with teachers of primary school revealed that many of them have never been trained either in algorithmics or in programming, and don't understand completely the goals and relation of the new topic to other parts of the curriculum. To prepare their lessons, they tend to use curriculum texts, teachers' guides, textbooks and existing online resources (that also propose mostly tasks of programming in Scratch). In spite of changes in French curriculum made in 2016, there are still many teachers of primary school who have not yet made lessons in this topic. This leads to the situations when in the same class of grade 6 (the first year of middle school) there are pupils with different levels of knowledge in algorithmics and programming.

We make the hypothesis that one of the ways to overcome the institutional constrains, to improve the teaching and, in consequence, learning of algorithmics, is the development of resources for teachers that takes into account different aspects of the notion of algorithm. However, the existed studies, like Aldon et al. (2017), showed that a teacher in interactions with a resource can interpret it in different ways. Sometimes, the didactical situation designed by a teacher on the base of a resource has different intentions comparing to the intentions of the authors of the resource. Thus, the elaboration of resources in algorithmics requires the design of tasks as well as the development of resources design principles that could "assure" their distribution and following usage with the relevance to initial learning goals. The research question that we investigate in this article is the following:

> What elements should contain a resource in algorithmics in order to support the learning intended by the authors of the resource, during its implementation by teachers who works in different contexts?

To contribute to this question, we investigate the design principles of a particular resource in algorithmics. In the next sections, we present the theoretical framework, the methodology choices and the project framework in which our study is anchored. Then, we propose some elements of data analysis and the corresponding results. In the last section, we answer the research question and draw our conclusions.

Theoretical framework

This study refers to the documentational approach to didactics (Trouche et al., 2018), which proposes a holistic approach to teachers' work, taking into account the new universe of resources to teacher use, design and re-design. The central role in this approach is given to the notion of resource that is used in the sense of a tool that "re-source" the teacher's work (Adler, 2000). In addition to the material resources (like textbooks, curriculum materials, etc.), this approach also takes into consideration such resources as discussions with colleagues and researchers, students' answers, etc. Teacher integrate resources in their system of resources and design on their base his/her documents related to a certain class of situations. In Pepin, Gueudet, & Trouche (2017), the notion of document is presented as a combination of the resources adapted and re-combined, the ways the teacher uses

them (which include the stable organisations of associated activities and particular usages), and contain the 'knowledge' guiding the usages.

The documentational approach to didactics provides the tools for following the evolution of a resource during its adaptation and usage by a teacher. As in this study we are also interested in the results of resource implementation in class, we refer to the theoretical framework of the structuring of the milieu as well (Brousseau (1998); Margolinas (1995, 2002); Bloch & Gibel (2011)). It allows to analyze both a teacher's and pupils' positions in a didactical situation. Thus, taking the pupils' point of view leads to bottom-up or ascending analysis starting from the moment when a generic pupil is confronted with a material environment (milieu), i.e. without *a priori* didactical intentions, to the institutionalization of knowledge, including the phases of experience or action during which the knowledge at stake is encountered. Top-down or descending analysis corresponds to the teacher's point of view. It starts from the confrontation of a teacher with a construction milieu in an unfinalized situation, includes the phases of development of teacher's global project (concerning a theme of study that involves one or several lessons) and local project (concerning a particular lesson), and ends with the devolution and observation of pupils' activities in a-didactical situation.

In our paper, we also use the notion of didactical bifurcation proposed by Margolinas (2005) for modelling the case when pupils confronted with a material milieu, invest themselves in a situation that is different from the one intended by a teacher. Margolinas distinguishes two types of marginal branches of a situation: a-didactical marginal branch (when pupils acquire new knowledge that is not in the teacher's project) and nildidactical marginal branch (when pupils don't acquire new knowledge). In analogy with the notion of didactical bifurcation, Aldon et al. (2017) proposed the notion of bifurcation of construction: when the construction situation (in which a teacher confronts with a resource and interprets its intentions for constructing his/her own project) carries the intentions distinct from those of the resource and, in consequence, it leads to a didactical situation different from the didactical situations potentially carried by the resource.

Methodology

Our study is anchored in the French PREMaTT project[1]. The objective of the project is to stimulate the collaborative design of resources for teaching, in a network of schools, supported by researchers and a monthly meeting in a "laboratory for innovative design" (Trouche, 2019). In particular, in frame of the project the teachers and researchers worked on the design of tasks and resources for teaching of algorithmics aiming to make them useful for other teachers. Collaboration between researchers and practitioners is widely used in design-based research for bringing solutions to problems of practice (in particular, by producing new artefacts) and for contributing in the research by identification of design principles.

Our methodology is based on the confrontation of *a priori* analysis (built around the intentions of authors of the resource's, analysis of the resource and situations carried by it) with a posteriori

[1] PREMaTT: thinking the resources of mathematics teachers in a time of transitions (http://ife.ens-lyon.fr/ife/recherche/groupes-de-travail/prematt)

analysis (built on the observation and analysis of implemented situations by ordinary teachers) as well as on the analysis of revealed dysfunctions, if any.

For our study, we constituted two teams. The first one involved a researcher and an experienced teacher who had been working part-time at a research laboratory and part-time in a primary school in the city centre for many years. The team worked on the design of didactical situations aimed to familiarize pupils with different properties of the notion «algorithm» and to show the role of algorithms in problem solving. The effectiveness of the developed tasks for supporting the intended learning was validated in result of confrontation of a priori analysis with a posteriori analysis of situations implemented in a class of grade 5 (10 years old pupils) by the experienced teacher.

The scenario of lessons developed by the team was chosen as the first version of the resource to transmit to the ordinary teachers. This choice was based on the hypothesis that this scenario, which takes into account both learning constraints and constraints of teacher practice, would constitute a sufficient support for teachers in order to design their own lessons project that will foster the intended learning. It included the description of the developed tasks (in particular, necessary material support, problems for pupils to solve, guidelines for teachers concerning implementation of the situations in class) and information about managing the lessons (timing, forms of class organization of pupils, etc.).

The second team involved three teachers (Natalie, Victor, Ida) who had been working together at a primary school in a socially disadvantaged part of the city for more than 5 years. The teachers obtained their initial education in different subjects[2]: Natalie in biology, Victor in literature and Ida in informatics. All of them at the time of the study taught in class of grade 5. Except Ida, who worked at the beginning of her career as a database operator for 10 years, the teachers have never been trained either in algorithmics or in programming. Natalie made a few lessons in programming in Scratch, while the others have never taught this topic. The teachers' mission was to prepare lessons using the scenario and to make them in their classes as well as to give the reflexive feedbacks during interviews and collective meetings with the first team. Ida, Natalie and Victor were also asked to elaborate a scenario that could be a possible continuation of the proposed one. The members of the first team didn't intervene in the work of the teachers (except a short presentation of the elaborated tasks by the researcher).

Collected data and their exploitation

For our study we collected the following data: answers of teachers to the questionnaire about their education, professional path, teaching experience, system of resources in mathematics and participation in collective work; video of collective work of Ida, Natalie and Victor before the implementation of the scenario in their classes; videos of the lessons of three teachers; pupils' written production; interviews with Ida, Natalie, Victor after the lessons; scenario proposed by three teachers as a possible continuation of the first one; videos of two collective meetings of the

[2] In France, in order to enter a teacher training program, candidates must have at least a Bachelor degree in any speciality.

members of both teams (the first one, concerning the results of the implementation of the scenario in three classes; the second one – a collective discussion about a possible continuation of the first scenario).

We used the lessons videos to make the *a posteriori* ascending analysis of didactical situations implemented by each teacher and confronted it with the *a priori* analysis. We were particularly interested in the episodes that show existence of pupils' activities that were not expected. In such cases we questioned the reasons of appearance of didactical bifurcations and identified the type of marginal branches (regarding the didactical project of the authors of the scenario). We used the video of class observations to analyse teachers' actions in the class (particularly, the devolution of the situations made by the teachers) and their possible influence on the appearance of alternative pupils' projections of a-didactical situation based on the material milieu. In the video of collective discussions of the teachers before and after experimentations as well as in the interviews with them, we were looking for episodes that could bring to light the logic of their actions in class and their choices made during the construction of the situations on the base of the scenario. To understand teachers' considerations about the role and possible place of constructed didactical situations in their global project of teaching algorithmics and programming, we analysed the scenario developed by Ida, Natalie and Victor as a possible continuation of the first one as well as the video of its collective discussion. The revealed dysfunctions in construction of didactical situations (bifurcations of constructions) as well as in their implementation in class allowed to revise the design choices made a priori and to identify what elements were missing in the resource.

Analysis of lessons observations

Due to space restrictions, we present in this section the elements of the analysis of Ida's, Natalie's and Victor's lessons and show how it contributed to the identification of missing elements of the resource. We start from a short description of the first two situations proposed in the scenario. Then, we show how Natalie, Ida and Victor made the devolution of the second situation in their classes and the corresponding pupils' activities.

The proposed scenario included the sequence of situations with a-didactical dimension (Bloch, 2000) during the work on which pupils "re-invent" sorting algorithms. Implementation of the situations doesn't require a computer and propose the following material support: playing cards and grid with defined places for putting cards on it in an aligned list.

In the first situation of the sequence, pupils choose randomly 7 cards from 13 cards of one colour and put them face down on the grid. The goal is to sort the cards by returning only two cards at a time. The situation is used to introduce the material milieu (cards, grid and three allowed operations: "to take two cards", "to put them in the right order", "to place them on an empty place of the grid") and prepare pupils for the following tasks. The target knowledge includes the understanding that at a time one can put two cards in "local" but not necessarily in "global" (between all cards) order, as well as the comprehension of the possibility to sort the cards in a finite number of permutations using the defined operations. The results of experimentations in the class of the teacher from the first team showed that most of pupils' procedures in this situation are based on the usage of the memory.

In the second situation, one pupil should sort the cards of another one by giving him instructions with respect to the allowed operations. The pupil, who has cards, doesn't show their values to the pupil who gives instructions. All cards could be turned over only after the "pupil-speaker" says "stop". The objective of the task (that imitate, in some sense, the relation between a human and a machine) is to foster the development by pupils of sorting strategies that will be generalised in the following situations.

Natalie made devolution of the second situation, emphasizing on the phrases that pupils can use for giving instructions to their classmates: "take card number … and number … ", "put them in the right order", "place them on the grid", "stop". She highlighted that the use of other sentences is not allowed. The observation of pupils' activities in this class showed that all pupils invested themselves in the main branch (regarding the didactical project of the authors of the scenario) and were working on the development of sorting strategies.

Ida and Victor, while explaining the challenge of the second situation, mentioned only that pupils "will do the same thing like in the first task, but this time, there is one pupil who gives instructions and another one who executes them". They didn't discuss with pupils the phrases that they are allowed to use for giving instructions, emphasising only on the necessity that "the 'executor' have to do exactly what the speaker says" and "that it is very important to be precise in the language". Victor gave in his class the following criterion of success in the task: "if the cards are in the right order, it means that 'the speaker' was very good". Such devolution of the situation led to its different interpretations by pupils and evoked pupils' activities which were not intended by the authors of the scenario. For example, part of pupils in the class of Ida, for whom it was not evident which phrases to use, invested themselves in the nildidactic branch. They used the commands "exchange the cards" or "put back without exchanging", factually trying to guess if the cards, they claimed to take, are in the right order or not. In the class of Victor, we observed one pupil who was searching for the optimal formulation of the sentence for sorting the cards of his classmate. He proposed the following solution: "you take two cards that you want, sort them and put them on the grid, and you continue like this until all cards will not be in the right order". This answer was not accepted by Victor which produced a protest from the pupil who was sure of the correctness of his answer.

Thus, in the classes of Ida and Victor we identified the marginal branches that were not expected by *a priori* analysis. It happened due to the way chosen by the teachers for the devolution of the situation. The following analysis of collected data showed the differences between Ida's and Victor's interpretations of the objectives of the first two situations with those intended by the authors of the scenario. For example, Victor, expecting that pupils would find the sorting strategies during the work on the first situation, saw the goal of the second one in the development of pupils' competencies to verbalise the solving procedures. This explains his choice of devolution for the second situation, when he left open the possibility of different formulations of pupils' strategies.

The obtained results of the analysis contributed to improve the resource. More specifically, the identified bifurcations of construction showed the necessity to describe the expected pupils' procedures in the first situation and the target knowledge in the second one as well as to provide the

help for the devolution of the second situation (to insist on the "authorised" sentences for giving instructions with a link to the property of feasibility of algorithm).

Discussion and conclusion

Our study puts the light on certain difficulties that teachers of primary school could have in interactions with resources in algorithmics (and, more generally, with resources that involves the concepts in which teachers don't have enough knowledge) and their influence on pupils' learning. In the case of Victor, flaws in a priori analysis of the proposed situations (in particular, wrong anticipation of possible pupils' procedure and identification of target knowledge) led to the construction of a didactical situation distinct from the one supposed by the authors of the resource. In consequence, the evoked learning activities of pupils didn't comply with intended ones.

It seems, that more pertinent choice of devolution of the second situation made by Natalie could be explained by the fact that she had taught a few lessons in Scratch before the experimentations took place and, as she said, "the usage of the given phrases for sorting cards is similar to the usage of blocs in Scratch for constructing a program". However, we also identified a few dysfunctions in her class that could influent on the learning outcomes. For example, Natalie didn't recognise in the pupils' answers the "germs" of the sorting algorithm with which she was not familiarized before. Hence, she didn't take them into account in the validation phase. Another example, which is common for the lessons of three teachers, is the lack of decontextualization in the phases of conclusion.

From the interview with Ida, Natalie and Victor as well as the analysis of the scenario proposed by them as a possible continuation of the first one, we draw the conclusion that they don't see all didactical potentiality of the resource proposed by the first team, focusing mostly on the effectiveness aspect of algorithm (Modeste, S., 2012). Moreover, analysis of the collective discussion about the possible prolongation of the first scenario showed that the situations, even didactically pertinent, could be discarded by the teachers if they don't see the connection between the target knowledge and curriculum requirements.

Revealed dysfunctions pointed to key elements to transmit to teachers by means of a resource in algorithmics in order to support the intended learning: *a priori* didactical analysis of situations proposed by a resource; target knowledge and ways of its gradual decontextualization in class; principal results of experimentations carried out in class (e.g. the examples of pupils' procedures, frequent errors, etc.); information regarding the basic theoretical and epistemological aspects of concepts involved in a resource; possible place of a resource in learning progression with link to curriculum requirements. Due to the fact that the transmission of the mentioned elements by means of a particular resource could make it too long and, in a result, not usable by teachers, the question of the structure of a resource in algorithmics need to be addressed.

Results presented in this paper, concerned only the first cycle of experimentation with the resource. The next step is to refine the design principles of a resource in algorithmics via the following cycles of experimentations with the revised resource as well as with other resources. Future work is also likely to investigate the impact of the resources designed on the base of the results of the study, on teaching and learning algorithmics at primary school.

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