WORKING WITH TEACHERS: INNOVATIVE SOFTWARE AS BOUNDARY OBJECT BETWEEN RESEARCH AND CLASSROOM

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This paper is based on an experiment of a small scale community around Casyopée, an innovative software for the learning of functions. A first assumption was that dissemination of research outcomes is possible through the development of communities involving researchers and teachers. Another assumption was that all teachers are not to be considered at the same level. "First-adopters" are teachers that chose to be associated with the project development from the beginning. "Mid-adopters" are teachers that can be interested by using innovative software in the classroom, but will choose to do it only when it brings a real added value. All other teachers potentially users of Casyopée make a third layer. This paper is a first step in the study of communication and collaboration in a "multi-layer" community.

INTRODUCTION AND FRAMEWORK

Relatively to the integration of digital environments in mathematics teaching and learning, the gap between researchers' expectations and the reality of classroom uses is often stressed. For instance Miller and Glover (to appear) regret that "*many teachers make progress using the presentational capability of interactive whiteboards but that failure to use associated digital technologies (…) lead(s) to wasted opportunities*". Among the opportunities wasted, I count the difficult diffusion of innovative software designed by research. Innovative tool design and diffusion is an important dimension in Mathematics Education research. The European project ReMath (IST4-26751) worked in this dimension, developing six 'Dynamic Digital Artefacts' (DDAs) and offering associated materials for classroom and teachers. Although a first start, this one way communication from research to teachers is not sufficient and an assumption is that the diffusion of innovation produced by research is better achieved through communal work involving researchers and teachers. The aim of this paper is to present the outcomes of such communal work around one of the ReMath DDAs: Casyopée. The conceptual framework guiding this work involves the notion of "boundary object" providing a "generalised mechanism for meanings to be shared and constructed between communities" (Hoyles, Noss, Kent 2004). We follow Fuglestad, Healy, Kynigos and Monaghan (2009)'s idea of using this notion to make sense of the collaboration between researchers and teachers in the integration of technology. Another notion is 'activity' that is to say what a subject or a group develops and controls when performing a task. According to Rogalski (2004) activity both affects situation and subject through the results on the objects of the situation and through the effects on the subject. The idea is then that, beyond the diffusion of a DDA, communal activity will affect researchers and teachers, and that studying the effects will improve the understanding of how innovation provided by research can disseminate towards classrooms. To analyse this activity, I will use the notion of praxeology (tasks, techniques, theories), that Lagrange (2000) borrowed from the Anthropological Theory of Didactics in order to make sense of the impact of technology on school mathematics: technology introduces new techniques, concurrent to

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existing ones, and then most often requires to reconsider praxeologies that are crucial tools in teachers' hands when they to organize students' learning.

CASYOPÉE AND CAS: EPISTEMOLOGICAL CHOICES AND CONSTRAINTS

Casyopée has been developed for ten years in a project involving researchers from the Didirem team and teachers after they experimented with 'standard' Computer Algebra Systems (CAS). The aim was to take up the challenge of teaching about functions at upper secondary level. The team was concerned that while technology is able to offer multi-representational and symbolic manipulative capabilities very effective for solving problems and learning about functions, no tool really adapted presently exists for students' use. CAS are designed for more advanced users. Dynamic Geometry (DG) offers means for constructing operational figures and exploring co-variations and dependencies in these figures, but exploration is limited to numerical values. Students are neither encouraged nor helped to use algebraic notation and to work on algebraic models. The focus of ReMath was upon computer representations of mathematical objects. Thus it was an opportunity to extend Casyopée's representational capabilities, in order to consider functions as models of non-algebraic dependencies. The choice has been to consider 2D geometry and magnitudes as a field of experience. The result is that Casyopée has now two main windows. In the symbolic window the fundamental objects are functions, defined by their expressions and domain of definition. Other objects are parameters and values of the variable. Casyopée allows students to work with the usual operations on functions like: algebraic manipulations; analytic calculations; graphical representations; support for proof… A new window offers usual DG capabilities and also distinctive features: geometrical objects can depend on algebraic objects and it is possible to export geometrical dependencies into the symbolic window in order to build algebraic models.

On the one hand, these epistemological choices are consistent with the notion of function as considered at secondary level and thus they should facilitate Casyopée's integration. On the other hand these choices introduce non trivial constraints and differences with software tools generally proposed for classroom use at this level. First, offering symbolic calculation has been decided in order to help students to identify the different stages in a solution of a problem; this decision also implies that Casyopée relies on computer algebra algorithms which are not always deterministic: for instance, it happens that two expressions are mathematically equivalent but also that none of the algorithms implemented in the computer algebra kernel can recognize the equivalence. More generally, Elbaz-Vincent (2005) points out the "decidability limitation" inherent to computer algebra, and concludes that an 'intelligent usage' of CAS in mathematical courses is not obvious. Second, DG in Casyopée is designed to help students in modelling algebraically geometrical dependencies. This implies to carefully distinguish between "variable objects" involved in the dependency and "generic objects" that have to be handled as parameters of the problem (Lagrange, Artigue 2010).

DISSEMINATING CASYOPÉE; GOAL AND METHOD

In the process of diffusion of an innovation, potential actors and their cultural context are to be carefully identified. Teachers that have been associated with the project development can be considered as “first-adopters”, or “experts”. I consider also “mid-adopters”, that is to say teachers that can be interested by using innovative software in the classroom, but will choose to do it only when they will be convinced that it brings a real added value to their teaching strategies. All other teachers potentially users of Casyopée (that is to say, every mathematics teacher at upper secondary level) would make a third layer. The idea is then to use classroom scenarios as means for communicating between layers: the elaboration and experimentation of scenarios by mid-adopters would be first a way of collaborating between experts and mid-adopters: mid-adopters would propose uses corresponding to their needs and ask the experts for their advice and support. The scenarios would be built in order to be proposed to all teachers and thus designed as a way to communicate between the second and third layer. The goal of the research was then to investigate what particular approaches those “mid adopters” take when working at these interfaces with the first and the third layer. A first hypothesis was that the design of scenarios with the help of experts would help the understanding of Casyopée’s potential and constraints. The second hypothesis was that the mid adopters would adapt the use of the software to their needs and sensibility. I expected that these teachers would be primarily interested in easy-to-achieve and close-to-curriculum applications of Casyopée, and sensible to problems and constraints related with the time required by implementing technologies in their classes, with curriculum requirements, with training needs, etc. Thus their production would provide useful material for an easy integration by teachers in the third layer.

For this study, the first-adopters or “experts” were two teachers that had been involved in the cyclical process of specifying functionalities for Casyopée, contributing to the software development, and experimenting with their classes. Crucial steps in the project were undertaken as a consequence of dissatisfactions they expressed after classroom experimentations. The decision to develop a software environment around a symbolic kernel for classroom use of symbolic computation derived from the difficulty they felt when using standard CAS. The decision to append a DG window was taken after a long term experiment about modelling geometrical dependencies in their tenth grade classes. B

In the same region of Brittany where the experts teach, a group of six teachers had been constituted in the IREM (Institute for Research in Mathematics Teaching) to experiment the use of the Interactive White Board (IWB). During two years they used software packages (DG and CAS) on the IWB and they were keen to enter a new project. For me they were good candidates to be “mid adopters”: they were convinced that technology can support mathematical teaching and learning, they were relatively experienced in the classroom use of technology but were not involved in Casyopée’s history. I refer to these teachers as “group members”.

The region of Brittany was developing its professional platform for teachers, students and families. The group could use this platform for its internal communication, but also for communicating with all mathematics teachers in the Brittany region. The third layer was then mathematics teachers at upper secondary level in the Brittany region, a group of around 500 teachers.

The group met 14 times along two years in 3 hour sessions gathering researchers, the two experts and the six group members. Six experimentations of scenarios were done in common, one group member offering his class and the rest of the group acting as observers. Communication between the sessions was done via the professional digital platform using a virtual group feature.

DATA ANALYSIS

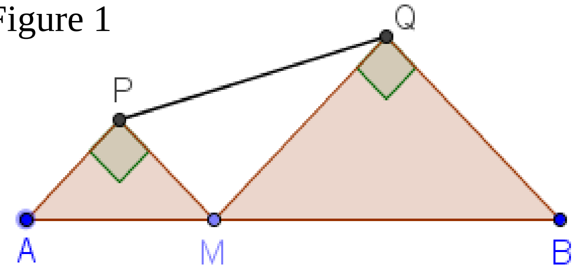
Given my focus on activity, I choose to analyse objective elements accounting for the communal work especially the video recording of the meetings. I coded the recordings in a video analysis database and split each meeting into about 90 clips varying from ten to thirty minutes. Using keywords, I classified the clips in non exclusive categories. The recording of experimentations, the messages and files exchanged on the platform and the scenarios proposed and experimented by the group as published on the professional digital platform were used as complementary data. Due to the limited length of this paper, a comprehensive analysis of this date will be published elsewhere. Here I restrict to a presentation and a qualitative analysis of their occurrences. Note that Lagrange (to appear) analyses two cases of personal evolution of members through their activity in the group.

Technical aspects: Casyopée is an evolving project and although many efforts had been devoted to software development in ReMath, it could not be considered as an achieved stable environment. A consequence is that in the first year a good part of the discussions in the meetings was devoted to the software itself. These discussions and the pressure that group members put through the situations they wanted to implement implied more work on the software than expected. In the second year a significant part of the meetings was again devoted to comments and discussion by group members about the software in parallel with the preparation and exploitation of classroom experiments. After adaptation by the designers, the features in development were tested in the experts' classes, group members feeling they could not deal with provisional versions. Like in the first year, more efforts than expected had to be devoted to software development. After the classroom experimentations these efforts could be directed towards curricular conformity and students' understanding of commands as well as towards the general ergonomics.

Casyopée's potential and CAS constraints: Group members thought that a symbolic system like Casyopée would be particularly useful for problems with complicated algebraic calculations. That is why they proposed situations resulting in very complex expressions that the symbolic kernel and other modules of Casyopée had difficulties to handle. It took time for these teachers to realise how CAS' "decidability limitation" stressed above influence Casyopée's operation. For instance in the third meeting, a member expressed her concern that, for two functions with equivalent expressions, Casyopée was not directly able to recognize their equality, and that only one of the symbolic calculations provided by Casyopée returned zero for the difference. This concern was linked with the ambition to offer students realistic problems and views that Casyopée should be used to scaffold students' weakness in algebraic computation in these problems. But more often computations could not be entirely achieved by Casyopée. Situations had to be carefully adapted in order to articulate CAS and by hand calculation. Then group members realized the actual potential of symbolic computation in Casyopée: it does not everything by miracle, but it can help when one understands its limits.

<u>Casyopée's choices:</u> Constraints deriving from Casyopée's expistemological choices have been exposed above, especially the necessity of distinguishing between "variable objects" and "generic objects". For instance, in the second meeting a member protested that she could not implement Casyopée for an optimisation problem she used to propose her students (figure 1). She considered two free points in the plane *A* and *B* and a free point *M* on the segment [*AB*]. The exploration was done numerically like in other DG systems. After that, she wanted to take advantage of Casyopée for exporting the dependency into the algebraic window in order to solve the problem algebraically. She chose *AM* as the independent variable and the calculation : $\frac{AP^2+MQ^2}{2}$ as dependent variable. But Casyopée replied that the calculation depended of more than a free point and the exportation was unsuccessful. The member expected a function like $x \to \frac{x^2}{4}+\frac{(AB-x)^2}{4}$ but in Casyopée, functions cannot depend on geometrical objects. The approach is to define the two points *A* and *B* as coordinated points, possibly depending on a parameter representing the distance *AB*. For instance *A* might be at the origin and *B* might be (0; *a*). The same member met this issue when preparing a scenario for experimentation a year later. She saw a contradiction between the necessity of limiting the free points and the dynamic exploration of the figure that she saw important for the students.

Figure 1



M is a free point on segment [AB]. AMP and AMQ are two right-angled isosceles triangles. Is there a position of M where the sum of the areas is minimal?

<u>Usages and classroom situations</u>: Many situations proposed by the group members in the first meetings could not be directly implemented bringing evidence of misunderstanding of choices and constraints referred in the first two categories. The situations and the software had to be adapted together: situations had to take into account the fundamental choices and constraints, while software development could correct technical limitations or less central choices. In the second year, the appropriation of Casyopée by the group members progressed notably especially with regard to the relationship between the algebraic and the geometric windows. This appropriation was done through the preparation and experimentation of situations but also seems inseparable from the discussion on the software itself. Why is it designed like that? Could other options be decided? In the discussion, reference was often made to other CAS or DG.

<u>Scenarios and communication with other teachers</u>: Preparing the diffusion of Casyopée to mathematics teachers in Brittany was an objective of the project, and the experts and I often

insisted on. Despite this, there was no outside communication towards the third layer of teachers in the first year. The group members were reluctant to publish material not really achieved. They insisted on publishing reports on successful sessions with a deep didactical analysis, rather than "raw scenarios". They also stressed that they could not promote Casyopée without fully understanding its potential and operation. The communication through the professional platform was organised in eight high quality "mini web sites"[1]. Group members insisted on publishing detailed scenarios with precise objectives and account of the advantages brought by Casyopée. The group members' concern for a strong didactical added value clearly appears in these productions. It implied deep reflection after the experiments and could be achieved only by the end of the second year.

<u>Other software:</u> In many clips Casyopée is compared to other software offered for classroom use at this level. TiInspire was used by some group members, but abandoned because it is not free and considered too complex. This experience nevertheless brought questions about the validity of CAS for the classroom that group members tried to elucidate when discussing Casyopée use. Geogebra is popular by French teachers as a free DG, but group members saw limitations and were looking for Casyopée as a more mathematical and curriculum consistent alternative. Nevertheless they often mentioned Geogebra as easier to use.

<u>Differences experts-members:</u> Differences between experts and group members appear in many clips in conjunction with the topics referred by the above categories, giving evidence of how Casyopée's characteristics had been integrated by experts while participating to the design. The evolving state of Casyopée was not an obstacle when working with expert teachers who understood well the difference between fundamental choices and minor defects and adapted the scenarios accordingly. They were used to ask for corrections to the software and had a scheme for updating Casyopée on the schools' computers under short notice.

<u>General math education:</u>

DISCUSSION AND CONCLUSION

This experiment of a communal work about a "boundary" piece of software between researchers, experts and "mid adopters" is surprising in some aspects. First the appropriation of Casyopée by "mid adopters" was much slower than expected. As a difference with what was expected these teachers did not focus on easy-to-achieve and close-to-curriculum applications and very slowly engaged in communication with other teachers. They wanted first to have a clear appreciation of Casyopée's potential and implement situations with a strong added-value, consistent with this potential. This can be seen in the light of current praxeologies in the French upper secondary schools. The curriculum insisted on using technology in problem solving situations, but because current technology (spreadsheet, dynamic geometry) is mainly numerical, teachers saw its benefits for exploring and conjecturing properties. Teachers in France are also much attached to formal proof that numerical technology cannot support. That

[1] These web sites are internal to the Brittany professional platform, but can be accessed publicly via http://code.google.com/p/casyopee/wiki/Activites

is why current technological praxeologies separate two phases: one is the numerical exploration of a situation, generally ending by a conjecture and the second is the formal proof, generally done in paper pencil but sometimes aided by CAS. These praxeologies make relatively easily their way into practices, because teachers want to encourage students' exploratory activity while preserving formal proof practices that they see at the core of mathematics, and there is a wide range of applications. The "mid adopters" were teachers who really integrated these praxeologies into their practises but they were interested in going beyond, taking advantage of CAS potential.

From the beginning, the ambition of the Casyopéee project was to associate closely exploration and elements of proof in an authentic mathematical activity thanks to symbolic computation. Praxeologies and software design were conducted together by the designers (experts and researchers). Because Casyopée was a small project, this design restricted to a limited number of situations, especially optimisation problems, like in fig. 1. Another limitation is that although some efforts had been done in ReMath, designers did not see means for numerical exploration as central in the project. It seems that they were not fully aware of these limitations, thinking that, thanks to mid-adopters, the range of situations would rapidly expand, and that the power of symbolic computation would compensate for limited numerical means. They were also not aware that fundamental choices in Casyopée could be seen by mid-adopters as conflicting with exploration and deeply impacting their proof practices. Extending the range of situations actually implied to build new praxeologies, both with regard to current technological praxeologies and to existing Casyopée praxeologies, *and* to adapt software design. While the expected scheme was roughly that mid-adopters would propose "narrow" praxeologies, and that they would enhance these praxeologies, progressively understanding Casyopée's design, the reality was that this design appeared relatively constricted with respect to mid-adopter's expectations.

This experiment sheds lights on how mid adopters' activity implies a deep reflection on their expectations with regard to the software and a reconsideration of the tools' potential. In this communal activity, the designers become aware of the conceptual and practical work necessary for adapting a research prototype into a "real life" classroom tool. Fuglestad, Healy, Kynigos and Monaghan (2009) conceptualise the work between researchers and teachers, using the term of "half baked" microworld. Casyopée was not conceived as a "half baked" microworld, but certainly one has to think of innovative software as a never finished product, evolving trough communication with users. As said in the introduction, I am interested in the gap between research expectations and the reality of classroom use of technology. This experiment can help to identify reasons for this gap, because it shows that "mid-adopters" and designers have to work out new itineraries in order to take advantage of innovation and that this process is far from obvious.

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