MATHEMATICS FOR TEACHING: AN ANTHROPOLOGICAL APPROACH

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Introduction

The purpose of this paper is to analyse the literature about *mathematics for teaching* through the lens of Chevallard's anthropological theory of didactics. This literature usually considers that this knowledge has two components: some kind of 'purely mathematical knowledge' and mathematical knowledge used in teaching. I will argue that this distinction is not appropriate, because mathematics does not live in vacuum but inside institutions. In teacher education institutions, mathematics should be taught for the intent of teaching.

Subject Matter Knowledge and Pedagogical Content Knowledge: early steps

The problem of teacher's knowledge for teaching was raised for the first time by Lee Shulman in 1986 (Shulman, 1986, 1987), in connection to the new reform in the USA. He asked the following questions:

> What are the sources of the knowledge base for teaching? In what terms can these sources be conceptualized? What are the implications for teaching policy and educational reform? (1987: 1)

As an answer to these questions, Shulman (1986) defined three categories for this knowledge: subject matter knowledge (SMK), pedagogical content knowledge (PCK), and curriculum knowledge.

Here I will focus on the first two aspects of this knowledge, SMK and PCK.

Subject matter knowledge (SMK). Shulman argues that teachers' content knowledge should not be limited to knowledge of facts and procedures, but requires an understanding of both the substantive and the syntactic structures of the subject matter.

> The substantive structures are the variety of ways in which the basic concepts and principles of the discipline are organised to incorporate its facts. The syntactic structure of a discipline is the set of ways in which truth or falsehood, validity or invalidity, are established (1986: 9).

This description of SMK is very important in mathematics education, because in many countries the teaching of mathematics does not take into account these two structures. Facts and procedures are usually taught without linking them, and well established demonstrations are usually taught to students, but there are no specific methods to prove the validity of some mathematical statement. As a consequence teachers understand *that* something is so, but not *why* it is so to use Shulman's terms, not only in developing countries as Mozambique (Huillet, 2007) but also in developed countries (see for example Proux, 2007).

Pedagogical content knowledge (PCK). Shulman highlights the special interest of pedagogical content knowledge,

> because it identifies the distinctive body of knowledge for teaching. It represents the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction (1987: 8).

This idea was quite new in the 80s, because content and pedagogy were usually considered separately in teachers training. A teacher was required to have a strong mathematical knowledge of the discipline(s) to be taught, and some general pedagogical knowledge, but the idea of blending content and pedagogy was not present (and is still not) in many teacher training courses.

Shulman (1986) describes pedagogical content knowledge as including

> for the most regularly taught topics in one's subject area, the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations – in a word, the ways of representing and formulating the subject that makes it comprehensible to others (1986: 9).

It also includes "an understanding of what makes the learning of specific topics easy or difficult" (1986: 9).

Ball, Thames and Phelps (2007) pointed out that the work of Shulman and his colleagues brings two central contributions to the field: they "reframe the study of teacher knowledge in ways that included direct attention to the role of content in teaching" (2007: 6), and they "represent content knowledge as a special technical knowledge key to the profession of teaching" (2007: 7) [1].

Shulman's descriptions of the knowledge needed by a teacher have been further used and developed by several mathematics educators, not only in mathematics but also in other disciplines, for example in chemistry (Davidowitz & Rollnick, 2005) and in physics (Jita & Ndlalane, 2005). Here I will focus on the studies on mathematics for teaching based on Shulman's ideas.

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[1] For a detailed description of Shulman's notions of SMK and PCK and further developments, see Ball et al. (2007)

SMK and PCK: further developments in Mathematics Education

Ruhama Even

In line with Shulman, Even (1990; 1993) divides the knowledge that a teacher needs to teach a specific concept, in terms of SMK and PCK. She builds an analytical framework for SMK for teaching a specific mathematical topic, which she applies to the study of the function concept. Within this framework, seven main facets of this concept are considered: essential features, different representations, alternative ways of approaching, the strength of the concept, basic repertoire, knowledge and understanding of a concept, and knowledge about mathematics.

The analysis of this framework and its application to the limit concept (Huillet, 2007) show that, although this description points out critical aspects of a mathematics teacher's knowledge, this classification does not appear to be systematic. Only two categories, the strength of the concept, and knowledge about mathematics, strongly refer to SMK. Four other categories both refer to mathematical and pedagogical knowledge, and can be seen as belonging both to SMK and PCK: essential features, linked to students' concept image; different representations; alternative ways of approaching the concept; and basic repertoire. They all refer to teaching practice. The seventh category, knowledge and understanding of the concept, refers to the quality of teachers' knowledge and not exactly to the content of this knowledge.

To conclude, I would say that, within Even's framework, the distinction between SMK and PCK is blurred. This could be because it seems difficult to describe SMK without reference to teaching practices.

Barbara Ball and her research team

Ball and her colleagues focus on the work that primary school teachers do in practice in the classroom, in order to develop a "practice-based theory of mathematical knowledge for teaching" (Ball, Bass and Hill, 2004: 55). And they ask the following questions:

- What mathematical knowledge is entailed by the work of teaching mathematics?
- What and how is mathematical knowledge used in teaching mathematics? How is mathematical knowledge intertwined with other knowledge and sensibilities in the course of that work? (2004: 55)

Using Shulman's division between SMK and PCK, they distinguish two components of SMK: Common Content Knowledge (CCK) and Specialized Content Knowledge (SCK).

CCK is defined in different ways in different papers:

- "the knowledge that one expects mathematically literate non-teaching adults to hold and also represents the content traditionally taught to middle school students" (Hill, 2007: 98);
- "the knowledge of the subject a proficient student, banker, of mathematician would have" (Hill, Rowan

and Ball, 2005: 373);

- "the mathematical knowledge and skill used in settings other than teaching" (Ball et al., 2007:32).

In contrast, the corresponding definitions of SCK are similar to one another.

- "the knowledge that one expects mathematically literate nonteaching adults to hold and also represents the content traditionally taught to middle school students" (Hill, 2007: 98);
- "the knowledge of the subject a proficient student, banker, of mathematician would have" (Hill, Rowan & Ball, 2005: 373);
- "the mathematical knowledge and skill used in settings other than teaching" (Ball et al., 2007:32).

While it seems relatively easy to describe SCK as the mathematical knowledge that teachers need to conduct their work, describing CCK seems to be problematic, as we can see by the very different explanations given, and as Ball and her colleagues themselves acknowledge:

> We have been most stuck by the relatively uncharted arena of mathematical knowledge necessary for teaching the subject that is *not* intertwined with knowledge of pedagogy, students, curriculum, or other non-content domains." (Ball et al., 2007: 40)

Here again it seems difficult to define some kind of 'purely mathematical' knowledge out of any practice, and the different explanations given for CCK all refer to some setting: everyday life, bank, student work, mathematician work.

Ball and her colleagues also introduced a new notion for describing mathematics for teaching: the idea of 'unpacking' (Ball et al., 2004). They argue that in advanced mathematical work, knowledge is 'compressed' and that teachers need to 'decompress' or 'unpack' this knowledge for their students. I will expand on this important notion later.

Jill Adler and the Quantum project

The Quantum project looks at mathematics for teaching in current teacher education practice in South Africa through the analysis of formal evaluative tasks in several institutions (Adler and Davis, 2006). They classify these tasks according to their mathematical and teaching components, looking more specifically at the demand of 'unpacking' of the knowledge of the task. They conclude that the mathematical knowledge privileged in most of the tasks is *compressed* mathematics.

Is compressed mathematics (or in Shulman's terms the substantive structure of mathematical knowledge SMK, CCK or 'purely mathematical knowledge'? Why this difficulty in describing 'purely mathematical' knowledge? Does this knowledge exist? I will examine these questions from an anthropological point of view, using Chevallard's anthropological theory of didactics.

Chevallard's anthropological theory of didactics

Chevallard locates the mathematical activity, as well as the activity of studying mathematics, within the set of human activities and social institutions. According to this model, any human activity can be subsumed as a system of tasks (Chevallard, 1999; Bosch and Chevallard, 1999). Inside a given institution, there generally are one or few techniques recognized by the institution to solve a task. Each kind of task and the associated technique form the *practical bloc* (or know-how) of a *mathematical organisation* (MO).

The institutional relation to an object is shaped by the set of tasks to be performed, using specific techniques by the subjects holding a specific position inside the institution. In an institution, a specific kind of task is usually solved using a single technique. Most of the tasks become part of a routine, the task/technique practical blocks appearing to be *natural* inside this institution.

However, there is an ecological constraint to the existence of a technique inside an institution: it must appear to be understandable and justified (Bosch and Chevallard, 1999). This is done by the technology, which is a rational discourse to describe and justify the technique. These ecological constraints can sometimes lead to a contradiction, given that the ability of students to understand will be constrained by their age and previous knowledge. It can be difficult for a technique to be both understandable and justified at the same time.

The technology itself is justified by a theory, which is a higher level of justification, explanation and production of techniques. Technology and theory constitute the *knowledge block* of a MO. According to Chevallard, the technology-theory block is usually identified with *knowledge* [un savoir], while the task-technique block is considered as *know-how* [un savoir-faire] (1999).

The two components of an MO are summarized in the diagram below.

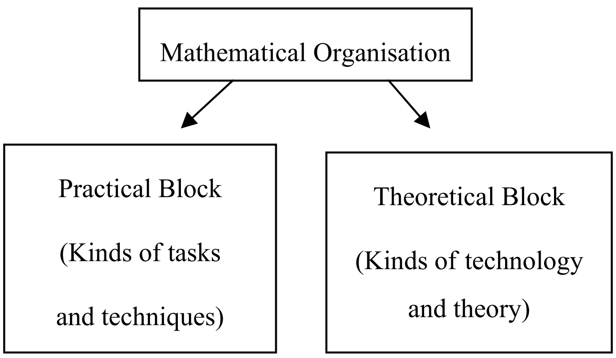

Figure 1 Mathematical Organisation

In order to teach a mathematical organization, a teacher must build a *didactical organisation* (Chevallard, 2002). To analyse how a didactical organisation allows the set up of a mathematical organisation, we can first look at the way the different moments of the study of this MO are settled in the classroom. Chevallard (2002) presents a model of six moments of study as follows: *first encounter* with the MO, *exploration of the task* and *emergence of the technique*, construction of the *technological-theoretical block*, *institutionalisation*, work with the MO (particularly *the technique*), and *evaluation*. The order of these moments is not fixed. Depending on the kind of didactical organisation, some of these moments can appear in a different order, but all will probably occur. For example the study of mathematical organisations at university level is often divided in theoretical classes and tutorials. The theoretical block is presented to students in lectures, as an already produced and organised knowledge, and tasks are solved using some techniques (practical block) during tutorials. In that way there is a disconnection between the theoretical component of the organisation and its applications.

Why and how does Chevallard's anthropological approach help to analyse mathematical knowledge for teaching

The notion of mathematical organisation

Even's analysis aims to build an analytical framework for teaching a specific *topic* in mathematics. In fact, most of the seven aspects presented as the main facts of teachers' SMK about a topic refer and are applied to a concept, in this case the concept of function. These are essential features, different representations, alternative ways of approaching a concept, the strength of the concept, knowledge and understanding of a concept.

Basic repertoire refers to principles, properties, and theorems, and their applications to several kinds of tasks, while knowledge about mathematics refers to the nature of mathematics, the ways, means and processes of production of mathematical knowledge, being "meta mathematics", which transcends a mathematical *concept* and even a mathematical *topic*.

Ball et al. (2004) also refer to a *topic*, beginning their paper with the analysis of the specific mathematical topic of multiplication of decimals. They then refer to teachers' mathematical knowledge of the *content*.

The introduction of the notion of mathematical organisation (MO) is helpful from two points of view. On the one hand, it helps clarify the focus: *concept* is restrictive because it indicates only one kind of mathematical object, *content* is less restrictive but not clearly defined. Chevallard defines a MO as the mathematical reality which can be constructed in a classroom where a specific content is studied (1999). In that way a MO is located within a specific institution and the same content can give rise to different MOs, depending on the institution where it takes place. It can be very specific, for example the multiplication of decimals; it can be less specific, referring to a more complex MO such as limits of functions in Mozambican secondary schools; and it can also be much more general MO, for example Calculus.

On the other hand the notion of MO re-locates mathematical activities within the core bosom of human activities. It is a special kind of praxeology.

The notion of praxeology

Chevallard considers that any human activity can be analyzed using only one model, which he calls praxeology, because it has two components: a practical block (praxis) and a technological-theoretical block (logos). For example for a very simple task such as "brushing your teeth", there exist some techniques and parents usually teach their children one of these techniques. They usually give an explanation as for example "you must brush your teeth and your tongue, to remove the bacteria and freshen your breath; otherwise you will have caries, tartar and bad breath". This is a technological discourse. This technology can be explained by chemical reactions between bacteria and the ivory. Most people do not have a precise knowledge of these chemical reactions, but they constitute the theory of this praxeology. Looking at a MO as a praxeology helps us clarify a teacher's tasks when constructing a didactical organisation, and consequently describe the mathematical knowledge needed to perform these tasks.

A new description of mathematics for teaching

The general task of building a new didactical organisation to teach a MO can be divided into several smaller tasks, according to the different moments of study (Huillet, 2007). The teacher has to:

1. Introduce the mathematical organisation to his/her students (first encounter with the MO);
2. Introduce some tasks and some techniques to solve these tasks (practical block);
3. Justify and explain these tasks and techniques through a technological discourse (knowledge block);
4. Make clear what students need to know (institutionalisation);
5. Organise students' work of the techniques;
6. Evaluate the students.

What kind of knowledge does a teacher need to perform these tasks?

First of all, the teacher must choose a suitable way to organise his/her students' first encounter with the mathematical organisation. Therefore s/he needs to know several different ways of doing that, but s/he also needs to know his/her students' conceptions about this MO and related MOs, as well as the difficulties students usually face when studying it.

Then, to help his/her students explore the MO, the teacher must also be able to lead them to work with different semiotic representations. S/he must give them different kinds of tasks and lead them to use different techniques to solve these tasks, choosing a suitable technique for a specific task. This means that s/he needs to have a good knowledge of the different semiotic representations in which this concept can be studied, and an extended basic repertoire of tasks within these representations and to be able to shift from one representation to another

Then the teacher has to choose what technological elements s/he will give to his/her students, in order to justify and explain the techniques introduced to solve the tasks. Which definition of the concepts should be given to students, according to their age and to their previous knowledge? Which theorems, which proofs can justify these rules? Are students able to understand these proofs? If not, how can these rules be explained? Can a shift of semiotic representation help explain these rules? Here again the teacher needs a good knowledge of the MO to be taught, but also of different representations and students´ previous knowledge.

Therefore, the analysis of the knowledge needed by a teacher to set up a didactical organisation to teach a specific MO led to the following categories of mathematics for teaching (MfT):

(a) Strong mathematical knowledge of the MO taught within the institution; this includes definitions of concepts, theorems and their proofs, correct use of notations and symbols, as well as general knowledge about mathematics.
(b) Knowledge about the social justification to teach this MO: why is this MO taught at this moment in this institution? This includes its relations to other MOs, and its applications in everyday life, in mathematics, or in other sciences.
(c) Knowledge about how to organise the students' first encounter with this MO.
(d) Knowledge about the practical block of the MO (tasks and techniques); this includes a repertoire of different tasks using different representations, or to shift from one representation to another, and different technologies to solve these kinds of tasks.
(e) Knowledge on how to construct the knowledge block (technological elements to justify the techniques) according to learners' age and previous knowledge.
(f) Knowledge about students' conceptions and difficulties when studying this concept.

This description of MfT does not distinguish between mathematical and pedagogical knowledge, but rather considers that each of these aspects of MfT have the two components merged together, although some of these aspects are more mathematical and others more pedagogical.

How does this new description relate to other studies?

The above presentation of mathematics for teaching relates to descriptions provided by other researchers in several ways.

Ruhama Even

Most of Even's categories of SMK can be found in this new presentation of MfT. For example: the first encounter with a MO includes the way of approaching a concept; basic repertoire and different representations are included in the construction of the practical block; the strength of the concept is part of the social justification for teaching this concept. However, this analysis of MfT, based on teachers' tasks to help students perform the different moments of the study, structures Even's categories. These can be seen as analyses of parts of this new framework.

Barbara Ball and her research team

Ball and her colleagues provide a list of critical tasks that teachers have to solve in their classroom practice in order to 'unpack' the mathematical knowledge. Presented below are some examples of how they relate to Chevallard's theory.

Ball et al. (2004) contend that, when confronted with methods not met before, teachers must be able to analyse these methods, and decide whether they work, not only for the specific task solved by the student, but for all cases belonging to this kind of task. This relates to knowledge of several techniques to solve a task, and knowledge of the technologies which explain these techniques.

They also assert that teachers must be able to select definitions that are mathematically appropriate. "However, an additional criterion for a 'good' mathematical definition is whether or not it is usable by pupils at a particular level" (2004: 58). In that case, the content is a concept, and the teacher must be able to select a definition for students. Ball et al. (2004) mention two constraints, the definition must be both correct and usable, which relate to the two constraints identified by Chevallard (1999), not only for definitions but for all parts of the theoretical block of a MO, for example for demonstrations of algorithms, properties, and theorems: the theoretical block must be at the same time mathematically acceptable and understandable by students at a particular level.

As an example, Ball et al. (2004) analyse the multiplication of two decimals 1.3 x 2.7 (kind of task). Let's look at this example through the lens of the anthropological theory of didactics. This kind of task is solved using an algorithm: multiply 13x27, place the decimal two places from the right. In Chevallard's terms, this is the technique associated to this kind of task. They then emphasize that teachers should be able to analyse students' wrong answers, explaining why they are wrong, and using different representations to represent the meaning of the algorithm. These explanations and representations, which aim to explain the algorithm and its possible deviations, belong to the level of the technology. This article does not mention the level of the theory, which in this case could be a deep knowledge of the decimal system, in order to explain why this algorithm works. In fact this theoretical level is not understandable to primary school students, and it is probably why it is not in the focus of this paper.

What happens in practice is that mathematics teachers know the algorithm to perform multiplications of decimals (practical block), and might have studied the decimal system in advanced mathematical subjects during their mathematical course[2] (theory).

However a link is missing: how to use the theory in order to produce an explanation at the technological level, mathematically acceptable and understandable to students? This is what Ball et al. call 'unpacking', and that, in Chevallard's terms, could be called the technological discourse.

Two other aspects of teachers' work presented by Ball et al. (2004) can be analysed in terms of knowledge of the technological part of the MO. These are: teachers must be able to 'unpack' mathematical ideas through explanations and use of different representations; and teachers must help students connect ideas, build links and coherence in their knowledge.

Being able to produce a technological discourse would enable teachers not only to explain the procedures to their students, but also to explain their errors and to analyse other methods of solving a kind of task. What Ball and her colleagues developed with the notion of 'unpacking' can be seen as a deep analysis of what could be teachers' technological discourse in primary schools.

Jill Adler and the Quantum project

The Quantum project shows that, in teacher training courses in South Africa, the mathematical knowledge privileged in evaluation tasks is compressed mathematics. They give the following example of a task asking students to 'unpack' a technique (2006:16).

> In solving the equation $ax + b = cx + d$, we do things to both sides of the equation that can be "undone" (if we want).
>
> (a) Make a list of the things we do and explain how they could be undone.
> (b) You have to be careful about one of these steps, because, depending on the value of a and b, you might do something that results in something

[2] Many primary school teachers do not have a mathematical course and, consequently, do not reach the theoretical explanations for some techniques.

There is a technique to solve this kind of task, which teachers know how to apply. However, the demand in this task is that students be able to 'unpack' this technique, giving explanations at technological level. Here again the notion of unpacking can be seen as part of the technological discourse.

Conclusion and discussion

This paper analyses how the mathematical knowledge needed by a teacher has been described by several mathematics educators, all based on Shulman's argument that a mathematics teacher needs to develop a mathematical knowledge in ways appropriate for teaching. This analysis has been done through the lens of Chevallard's anthropological theory of didactics, looking at a teacher's task as the construction of a didactical organisation in order to teach a specific mathematical organisation to specific students inside a specific institution.

I argue that the distinction between 'purely mathematical' knowledge (SMK or CCK) and mathematical knowledge adapted for teaching (PCK or CCK) is not appropriate. Mathematics does not exist 'in vacuum'; it lives inside institutions, and must live in specific ways in teacher training institutions. This relates to the argument presented by Freudenthal (1985) in his book review of the first presentation of Chevallard's theory of the didactical transposition (Chevallard, 1985), where he questions the notion of scholarly mathematical knowledge (savoir savant) as the source of the transposition process.

This can also explain the difficulties faced by mathematics educators in describing some 'purely mathematical' knowledge (SMK or CCK) as a knowledge existing outside any institution. When constructing a didactical organisation to teach a MO within a specific institution, teachers use as their 'reference mathematical organisation' the knowledge learnt about this topic in the institutions in which they have met it: schools, university, books. This reference MO differs from teacher to teacher. For example, for a Mozambican teacher, the reference MO for teaching limits has essentially two components: calculations and formal proofs using the ε-δ definition. For a teacher from another country, the reference MO can be more elaborate, including for example how to use the numerical and the graphical registers. A Mozambican teacher's reference MO will enable this teacher to teach limits in Mozambican schools according to the syllabus and the institutional routines. It will not enable this teacher to challenge the institutional relation to this concept (Huillet, 2007). I would then divide the question of what kind of knowledge a teacher needs in order to teach a mathematical organisation into two:

- What kind of knowledge does a teacher need in order to teach a mathematical organisation to specific students in a specific institution, according to the institutional relation?

- What kind of knowledge does a teacher need in order to teach a mathematical organisation to specific students in a specific institution, challenging the institutional relation?

Obviously, the second question is much more challenging than the first one.

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