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Designing for communication at work: A case for technology-enhanced boundary objects

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ABSTRACT

In this article we conceptualise the challenges of communication between a mortgage company and its customers in terms of crossing boundaries between communities. Through an ethnographic study we first address the question: what are the challenges of communication between sales agents and customers of a mortgage company around mathematical artefacts? Insight into these challenges formed the basis for an intervention in which we designed technology-enhanced boundary objects (TEBOs) that were reconfigurations of problematic symbolic artefacts. Secondly, we ask what the sales agents learned from the intervention. The data suggest that the intervention with the TEBOs helped employees to develop a better understanding of the mathematics behind the mortgages they sold, and to improve communication with their customers.

1. Introduction

In sociocultural and cultural-historical theories, challenges in communication between practices are often conceptualised in terms of boundaries (Engeström, 2001; Wenger, 2000). In this paper we are particularly interested in the challenges in communication which arise due to the mathematical nature of the topics and means of communication. We choose to focus on the topic of *mortgage pricing* and on communities around and within a large mortgage company. The first purpose of this paper is to gain more insight into boundaries that arise between various communities around mathematical artefacts. In particular, we ask Question 1: *How can we characterise the challenges in the communication between sales agents and customers of a mortgage company around mathematical artefacts?*

The literature not only focuses on problems due to differences across boundaries, but also claims a learning potential *at* the boundary between communities of practice (e.g., Wenger, 2000) or activity systems (Engeström, 2001). In Engeström's Boundary Crossing Laboratories, contradictions between activity systems are used to create new objects that allow for the transformation of practices and thus learning (see also Kerosuo & Toiviainen, 2011). Apart from such laboratories few interventions have been carried out so as to exploit learning potential by means of a boundary-crossing approach that takes interaction seriously. It seemed plausible that a boundary-crossing approach between employees and ourselves as mathematics education researchers, focusing on symbolic artefacts and mediation through technology, could be a fruitful alternative to "direct teaching" of the mathematics behind workplace products or processes (Hoyles, Noss, Kent, & Bakker, 2010). The second purpose of this paper is therefore to explore the learning potential at the boundary between employees

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and ourselves as researchers in mathematics education, leading to Question 2: *What do sales agents learn from a technology-oriented boundary-crossing approach?*

In order to answer the first question we need to address the methodological challenges in identifying communication problems around workplace mathematics. Next, we delve more deeply into what we mean by a boundary-crossing approach to developing employees' understanding of workplace mathematics, and present some of the results.

2. Identifying communication problems around mathematical artefacts

When trying to identify problems in communication between various communities due to different orientations towards mathematical knowledge, we face a methodological challenge. Mathematical expertise is widely recognised as crucial for work (e.g., Confederation of British Industry, 2008) but the nature of this expertise and how it is actually mobilised in practice tends to be largely invisible both to users and observers. One source of this invisibility arises from the embedding of mathematics within the representational infrastructures of the models, tools and artefacts of the workplace (Hall, 1999)—a phenomenon sometimes referred to as "blackboxing" or "crystallisation" (Williams & Wake, 2007). The invisibility is compounded by the widespread avoidance of engagement in mathematical thinking in companies (Hoyles et al., 2010).

In the financial services sector, the focus of this paper, almost all calculations are undertaken by centralised computer systems. This not only frees employees from tedious work, but also ensures the correctness of financial calculations, a core regulatory requirement. However, this automation process has introduced further layers of invisibility between employees and the mathematical models embedded in the computer systems (Kent, Noss, Guile, Hoyles, & Bakker, 2007). In the face of competition and greater customer demand for business transparency, clear communication and flexible response, employees need to be able to articulate at least some of the relationships behind the models in ways appropriate to their audience. We have called this requirement for the interpretation of symbols in the context of technology "techno-mathematical literacies" (Hoyles et al., 2010).

Much of the research into workplace mathematics has addressed the methodological challenge of making embedded mathematics visible by focusing on disruptions in the routines of work, disagreements between communities as to actions, or where communication across different representational infrastructures proved problematic (Hall, 1999; Noss, Hoyles, & Pozzi, 2002). To these foci, we add a phenomenon that we characterise as "pseudo-mathematics", which poses a major challenge to developing necessary expertise for the workplace.

3. Boundary objects and a boundary-crossing approach

We came to focus on communication around mathematical artefacts that were intended as boundary objects—artefacts that serve to coordinate different perspectives of several communities (Star & Griesemer, 1989). Boundary objects are intended to be (or happen to be) flexible enough that different social worlds can use them effectively while being robust enough to maintain a common identity among those worlds. Boundary crossing can occur for example if boundary objects facilitate communication between and within different activity systems even if they do not and cannot entirely capture all that they are supposed to mediate (Cobb, McClain, de Silva Lamberg, & Dean, 2003). The particular class of boundary objects on which we concentrated were those expressed symbolically in graphs, charts, tables, figures or algebra. In these cases, the ambiguity inherent in a boundary object derived from the different meanings accorded to their symbolic representation.

In order to function in different communities, boundary objects need to be "full" (specific) enough to satisfy informational needs of each community, but leave room for local use and interpretation (implying some "emptiness" or lack of specificity). The challenge of our research can therefore be restated: what is it that makes intended boundary objects fail or succeed in communication? Analysing how people use them tells us what roles the boundary objects play, and thus what kinds of mathematical activity is, or is not, being carried out. This reconceptualisation in terms of boundary objects also helps to avoid simplistic conclusions regarding the apparent lack of employees' mathematical knowledge. Rather than focus on what people do and do not know, the issue in workplace communication is whether the mathematical artefacts used are sufficiently full so that the different communities are able work with them for particular purposes. (Note that the predicate "full" should not only be attributed to the artefact but also to the inferences drawn by people from the communities in which it is used; cf. Guile's, 2011, point on inference.)

The reconceptualisation of symbolic artefacts in terms of boundary objects also points to what a boundary-crossing approach to developing techno-mathematical literacies might be like. The goal is not to teach employees the mathematics behind such artefacts, but engage with the different meanings and perspectives in the pursuit of communication by means of dialogic reflection on these artefacts (cf. Akkerman & Bakker, 2011). As designers, we had to decide which aspects of mathematical systems behind these artefacts were useful for discussion and which could remain invisible. In other words, we aimed to make the boundary objects employees used slightly "fuller" (more specific) but no more than was necessary for work practice.

4. Methods

The data used in this article stem from a financial company providing a special kind of mortgage (i.e., a loan used to buy property), called the current account mortgage (CAM), which integrated a regular current account with the mortgage. In collaboration with the company we undertook our research in two phases. Phase 1 (2005) involved ethnographic case studies in order to characterise the kinds of mathematical thinking needed to function effectively in each workplace. Methods used included work-shadowing, analyses of documentation and semi-structured interviews with managers and a wide range of employees. We progressively focused on probing the meanings held by different employees of the symbolic artefacts that were supposed to convey information between communities. We also joined team meetings and listened to conversations with customers to ascertain if and when problems of communication might be arising and how employees reacted to them. As part of training sessions organised by the company, we also played the role of customers and thus had the opportunity to ask sales agents about quantitative aspects of the mortgages they were "selling" to us. This approach gave us an indication of the boundaries that can emerge between sales agents and customers, and hence of the potential challenges to effective communication between them.

In the second phase of the research (2006), we carried out iterative design-based research with our employer partners, to design learning opportunities that would address the challenges found in the first phase. These comprised activities aiming to make work process models more visible and manipulable through engagement with interactive software tools, which modelled elements of the work process, or were reconstructions of the symbolic artefacts from workplace practice that we had identified in the first phase as problematic mathematical artefacts. These software tools we named technology-enhanced boundary objects (TEBOs). They sought to model what we deemed to be the parts of a symbolic artefact that were central for effective communication with the added functionality to enable experimentation by, for example, changing relevant variables to make them more accessible and their effects more visible. These TEBOs were used in a 2-day course with eight sales agents, all of whom had a background in GCSE (general certificate of secondary education at age 16), with one who also had A-levels (pre-university track at age 18). We co-taught with the workplace trainer. Four weeks after the session, we interviewed the trainer and four participants to ask them to reflect on our course and to ascertain what they felt they had learned and whether the experience had made any impact on their work.

5. Communication involving pseudo-mathematical artefacts

Our observations in the company quickly focused on the telephone sales department. Here we identified an apparent need for techno-mathematical literacies among employees as they reacted to customer questions and attempted to give some explanations of the basis of mortgage payments. This was agreed by the workplace trainers. One of the key challenges we observed arose as the result of regulation that had been put in place due to miss-selling in the sector in the past: sales agents are not allowed to give *advice* to potential customers. Agents can provide "facts" only, usually presented in the form of an "illustration"—a scenario with computer-generated figures that recorded saving, interest rate, length of the mortgage for a single case. These "facts" only produced the results of particular cases. At no time did we encounter any communication that included any mention of the derivation of the specific case or the rule(s) underlying it. For advice, agents had to refer to financial advisers.

The regulation about only giving facts meant that answers could be given to straightforward questions such as: "With monthly payment X in how many years can I pay off my mortgage?", since the computer system could simply produce the result of the calculation. However, it was not possible to produce some structures to help agents ask more complex "what-if" questions. For example: How much will I save if I pay in a lump sum and take it out three years later? Customers who ask such questions are easily lost to the company if the sales agent cannot answer their questions. A sales agent commented: "It is mostly one shot and you get one go at it. If you can't give it [the answer] to them then and there, then they are not interested." The challenge illustrated here is that customers cannot be given a satisfactory answer to the questions they really want to pose, namely the what-if questions. Such questions are impossible to answer with the computer system the agents had to hand, such as the so-called "illustration tool", and additionally required some insight into the mathematical model behind the CAM.

In summary, we saw ample evidence that sales agents were not able to convince potential customers of attractive features of the CAM. This problem is part of the conceptual and social boundary between the agents and the customers. Our conclusion was supported by a survey carried out by one of the trainers among the managers. We cite a few sentences of his report to underpin the need for attention to relevant underlying mathematics and avoid where possible pseudo-mathematical interpretations:

- Most people didn't understand much of the maths that underpins the illustration.. . .Typically, they rely on the totals the screens give them and cannot make a "common sense" judgement as to whether the figures are realistic, correct or how to bring them to life. Many people we spoke to think the illustration is not correct.
- Making the figures meaningful is a *real* struggle—there are just too many of them and they read from the screen without understanding them. If these areas were understood, the communication would be considerably easier.

We now turn to more particular cases of mortgage retailing that formed the basis of the development of our learning opportunities. A typical first engagement of a prospective customer might have been through the publicity for the mortgage available in a customer booklet in which there was a graph showing an illustration of how the mortgage might be paid off using a typical repayment mortgage compared to a CAM. Fig. 1 shows the outstanding balance over a 25-year period; in the

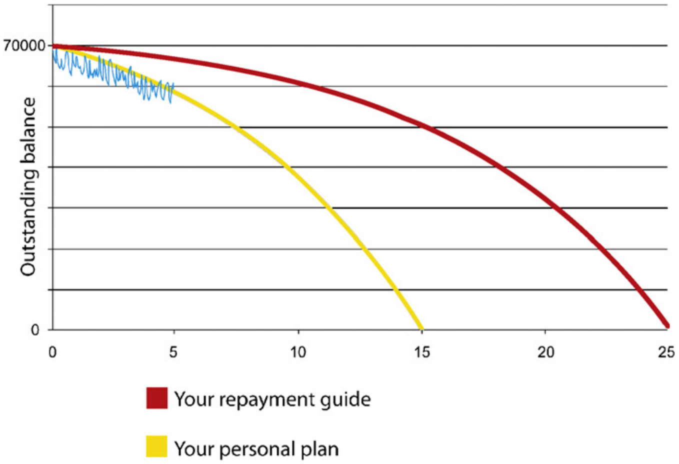

Fig. 1. A graph (reconstruction) showing a standard repayment scheme in 25 years (top line) and a personal plan of repayment in 15 years. The "wiggly" line over the first 5 years indicates the real outstanding balance over these years in the current account mortgage.

beginning paying off the balance is slow because most of the monthly payment to the bank comprises the interest. Later, the proportion of interest relevant to the capital is smaller so the graph goes down more steeply towards the end of the period.

As mathematics educators, we found the graph more curved than we expected for an interest rate of about 6%; a straight line would indicate 0% interest and a curved line as in Fig. 1 would require an unrealistically high interest rate—a message we assumed the company did not want to get across to customers. We (Res.) therefore asked an experienced employee (E) what he made of this graph and how he could read and interpret it:

Res.: What interest rate would you be paying do you think? [pointing to the top curve]
E: I haven't got a clue. The interest rate changes all the time and it depends on what product you're on as well.
Res. But if the interest rate reduced, what would you think would happen to this graph?
E.: [thinks] If the interest rate reduced, I guess it will still be spread over 25 years and that will still be curved because you are paying capital and interest. Regardless of whether or not reduced you will still have that same curve.

Interviews with other employees led us to a similar conclusion, namely that the sales agents were largely unaware of any but the simplest relationships between interest rates and repayment schemes, even though they were able to explain mortgages in general financial terms (e.g., capital and interest). When we tried to model the graph from the booklet to match the curvature, we found it would have needed an interest rate of about 14%! So our initial assumption that this graph represented the actual change in outstanding loan over time was unjustified. The graph was not understood by employees as a mathematical representation. In fact it could not be, since the variables determining it were hidden and the curvature of the graph based on a completely unrealistic set of such values. It is in this sense that we began to describe the graph as *pseudo*-mathematical: *mathematical in form but not in function.*

We should not jump to conclusions about the nature of communication problems with customers. We as mathematics educators had maybe read too much specificity into this artefact (the curvature as a measure of interest rate) where this was not its purpose in practice. Rather, one might consider that the graph was only meant to convey to customers that it was possible to pay off their mortgage sooner than in standard mortgage schemes and that their mortgage balance would fluctuate rather like a normal bank account (a less specific reading of the artefact). For example, a bonus would directly decrease their mortgage debt and help customers to pay off earlier and thus save money. One could therefore argue that this example, though pseudo-mathematical, does not necessarily hinder communication between the company and its customers. This is less likely for our next example.

Sales employees frequently talked to customers about comparing the costs of maintaining a credit card debt against the lower costs of consolidating that debit within a CAM. The CAM is cheaper because its interest rate is lower. However, this is obscured by the fact that mortgage interest is usually quoted as an annual rate (e.g., 5.9% APR) and credit card interest is usually quoted as a monthly rate (e.g., 1.8% per month). We expected that employees would be aware of the mathematical relationship that an annual interest rate is approximately but not exactly 12 times a monthly rate. In fact, this was not the case for all but one or two of the employees we encountered. Thus, the interest rate numbers were just perceived as labels attached to financial products: a "1.8% per month credit card" or a "5.9% APR mortgage" (annual). Even the trainer admitted that he had not thought about this issue before: "There is a complete misconception about this. And the only reason I picked it up is by having worked through your exercises myself, and realising that I had the same impression myself."

In the trainer's view, sales agents saw the different interest rates as labels for instruments: annual rates as labels attached to a mortgage arrangement or a savings account, monthly rates as labels attached to credit card or loan debts, without thinking through their mathematical meaning and the relationships that therefore exist between the values. Again the interpretation was not unmathematical but rather pseudo-mathematical: there was some ordering of the numbers 1.8 and 5.9 but no attention paid to % per unit of time. Specifically, the monthly and annual rates of the company were compared with those of other companies (lower is better), but not with each other. One of the goals of the learning opportunities therefore became to discuss the underlying mathematical relationships so that sales agents could point out customers the high interest rates on credit cards even if the label attached to it (1.8) seemed lower than that of the mortgage (5.9). In terms of boundary objects these interest rates were too ''empty''; this was confirmed by one of the trainers.

We concluded that a mathematical understanding of some features of CAM beyond one that was pseudo-mathematical could help sales agents explain to customers the benefits of the CAM, particularly to those who were rather wealthier and had fluctuating income. For example, CAM allows customers to consolidate expensive credit card debts with the mortgage and to pay a lump sum, say an inheritance, into the CAM without incurring charges. The company's own survey along with the findings of the first phase of our research provided the basis for ongoing collaboration with the company in developing learning opportunities to be used in a boundary-crossing approach. In the next section we give a few examples of such learning opportunities along with a summary of what participants believed they learned.

6. Communication around technology-enhanced boundary objects

We adopted a boundary-crossing approach by developing technology-enhanced boundary objects (TEBOs) as mentioned earlier; they modelled and opened up the problematic aspects of mathematical artefacts and tools identified in our first research phase. In the case of the mortgage company, we developed software that was a mixture of pre-written and learner-constructed spreadsheets to model the way the CAM worked. We did not bring all the mathematical details of the model into the foreground, but focused on the effect of interest rate, time of the loan and the effects of taking out more money—aspects that we knew would help agents communicate with customers.

One TEBO reconstructed the mortgage graph (Fig. 1) in a spreadsheet with all the input variables and calculations made explicit in order that the graphs could be produced according to the input variables that matched different customer scenarios. The whole structure was potentially modifiable by simple changes that could lead to models of more complex situations. For example, in Fig. 2, an inheritance of £20,000 was temporarily put into the account, which reduced the total mortgage interest and the overall time to repay the mortgage. The convenience of the spreadsheet was that the £20,000 could be literally dropped into the formula in the month 60 row (''...−20,000'') and taken out again in month 90 (''...+20,000''). A small shortening in duration of the mortgage was visible in the graphs. The spreadsheet also calculated the amount of interest saved by this offsetting—something customers sometimes asked but was not possible to answer with the available illustration tool.

A further activity aimed to bring together the issue of lifestyle (notably flexibility) with the mathematical interpretation of the graphs. It started with the graphs, and asked participants to match a given set of graphs against a given set of customer scenarios—see Fig. 3. An example scenario was:

> Miss Taylor is a self-employed landscape gardener. She has an annual tax bill that usually amounts to £3,000. She has a savings account into which she puts £250 regularly each month to pay her annual tax bill. After looking at a CAM she thinks she'd like to use her monthly savings to offset against her mortgage and to take £3,000 out of her CAM annually to meet her tax liability.

The participants had to read the graphs and match one to the situation; the graph at the top left is the correct solution. Although half of the participants initially felt uncomfortable or even anxious when dealing with the mathematics behind mortgages, they mainly considered this scenario-matching activity straightforward.

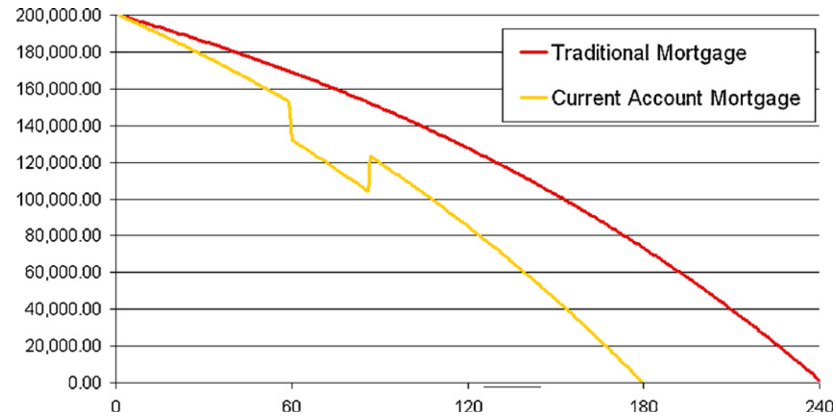

Fig. 2. A spreadsheet model shows the value of outstanding loan in £ versus months, and illustrates what happens when an inheritance of £20,000 is put into the CAM between months 60 and 90.

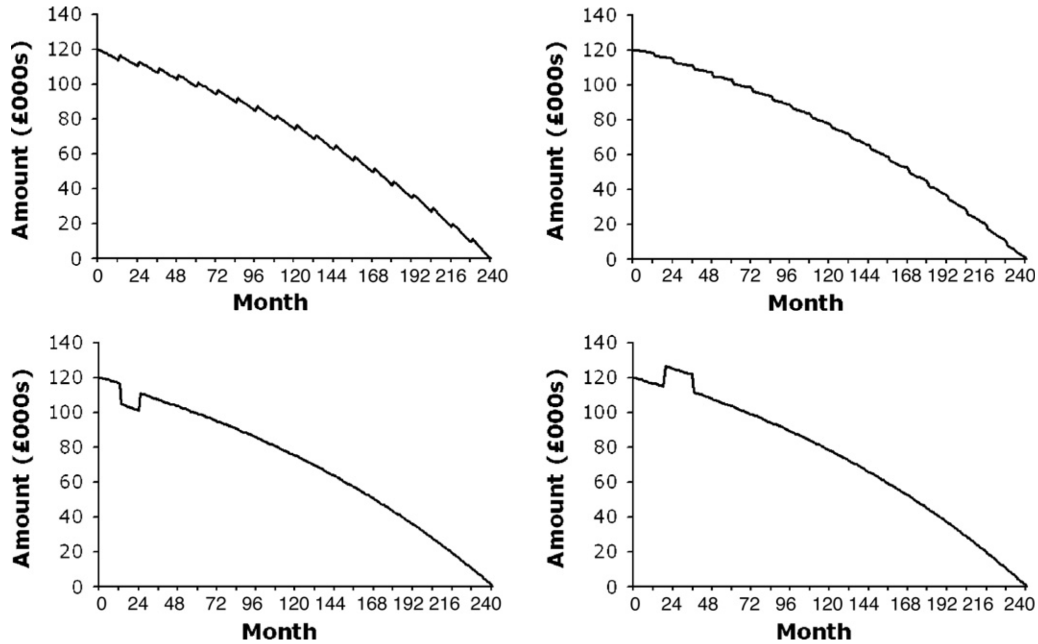

Fig. 3. Scenario-matching activity—each of a set of given graphs had to be matched against a given set of customer scenarios. The miss Taylor scenario fits the top left graph.

One further activity that proved useful to participants was on modelling credit-card debts. They discovered it takes forever to pay back these debts if only the obligatory monthly percentage of the debt is paid back. They also learned that annual rates are not exactly twelve times the monthly due to compound interest.

In the post-interviews the participants said they had developed better awareness of the mathematical background of mortgages, in particular the relationship between monthly and annual rates as well as compound interest. Sean [all names are pseudonyms] told us:

> My first customer [after the course] said, I have got my credit card, I am paying the minimum but he knew he was not going to pay it off even though it was only £2000. He realised that was going to take him forever so I am just going to get rid of it. He talked about compound interest a lot. It was quite good because we had gone from this training and that was my first customer. . . . I had a little chuckle to myself.

The trainer concluded: "So that was a clear piece of learning that you used then and I suppose you used that in a sense to highlight the benefits of the CAM."

Sandy also gave an example of feeling better prepared to talk to particular customers. Previously, she had accepted a 1.8% rate on a credit card as a given—a pseudo-mathematical label. Now she felt prepared to ask if this rate was monthly or annual, being able to explain that 5.9% per year is actually cheaper than 1.8% per month. The trainer commented:

> That is actually an example where you have learnt something and you have used it. If you did not have that understanding about that would you have thought to ask the question when the customer says, have you got a better deal or a better rate? So just by having an extra bit of knowledge it is helping you to pose questions.

The four interviewees thought they had gained confidence despite their initial anxiety in the course when asked to work with formulae in spreadsheets. However, two participants expressed frustration they were not allowed to use the spreadsheets in their communication to customers because these were not "signed off". Sandy:

> It was frustrating. It was really interesting to do [the learning opportunities] and we were starting to get into it, what would the graph look like if we do this or do that and then you just go back and all that sort of stuff that you learnt is lost.

The interviewees expressed the view that the spreadsheets allowed them to give more answers to customers' queries, but due to company regulations and the concern that agents might tell customers wrong information, the spreadsheets were not made available for general usage. However, one participant said he still used them for himself. This example illustrates how a possible impact of the learning opportunities on practice was hindered by company rules (cf. Daniels', 2011, notion of boundary strength). However, the company was working on a new illustration tool that would allow the flexible exploration of more customer queries.

7. Conclusions

We first asked: *How can the challenges in the communication between a sales agents and customers of a mortgage company around mathematical artefacts be characterised?* A first challenge was to give customers useful answers without giving advice. Sales agents had to respond to what-if questions that the computer system did not allow them to answer and they found it difficult to explain the attractive features of the CAM. The communication between agents and potential customers was mostly around symbolic artefacts that we found often failed in their intended role to convey particular messages to customers. They frequently seemed to impede rather than facilitate communication across communities. We found several examples where a lack of understanding the mathematical relationships between variables hindered the communication with customers. For such cases we developed learning opportunities that aimed to strike the balance between emptiness and fullness of the mathematical background of boundary objects.

We next asked: *What do sales agents learn from a technology-enhanced boundary-crossing approach?* Anecdotal evidence from interviews suggests that several sales agents felt more confident and better able to communicate with their potential customers. However, the agents felt constrained in their explanations to customers because they were not allowed to use our TEBOs when talking to customers: These TEBOs were not certified for such usage and financial regulations are very strict.

In summary, the approach we have taken was firstly to analyse the intended boundary objects in the communication between such communities and secondly to develop TEBOs that provide employees with learning opportunities to gain an understanding of the mathematical models behind the boundary objects. A similar boundary-crossing approach in the car industry also yielded some evidence that the approach is promising for fostering learning at the boundary between different communities (Bakker, Kent, Noss, & Hoyles, 2009). In this way we deploy the advantages of technology – as opposed to the static boundary objects employees often work with – to foreground precisely the mathematical structures that are necessary for engagement. It is in this way that employees can build on their pseudo-mathematical knowledge of the products they make or sell by improving their techno-mathematical literacies. This would then help them make better use of intended boundary objects and better communicate with their customers.

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