Towards a multimedia tool for numeracy education

Kees Hoogland

APS - National Center for School Improvement,
Utrecht, the Netherlands
K.Hoogland@aps.nl

The numerate thinking of individuals takes place in many situations. To study this individual numerate thinking, it must be made visible and observable. This paper reports on a Dutch research project on the numerate thinking of young adults in vocational education. In the course of this research, an interview technique was developed to gain a clear picture of the numerate thinking of the respondents. An essential element of this technique was to place the respondents in an emotionally safe setting, where they felt free to talk openly about their thougth and actions in all kind of situations. In addition, an instrument was developed to identify, categorise and analyze the numerate thinking of the respondents in the interviews. Based on the results of the work with this instrument, a set of design principles was construed for the development of a web-based multimedia learning tool. The aim of this tool is to empower its users with knowledge and skills for coping with situations that call for numerate thought or action.

This paper reports on the development of an instrument to identify and analyze the thinking of individuals in situations that call for numerate thinking. The exploratory research for the development of the instrument was carried out with students and young adults. The instrument is founded on frameworks developed in research on adults learning mathematics. The findings of the study may be of particular interest to those who work with adults on numeracy in educational settings that are closely related to work or the activities of daily life.

The research, and the development of the instrument, also served as building blocks for a set of design rules for the development of learning tools. This follow-up work on practicable learning tools is motivated by the idea that

> research must be closely linked with practice in a field where development and improvement in practice have priority status. (Fitzsimons et al., 2003, p.117)

The learning tools are designed in such a way that they are closely connected with the numerate thinking of individuals in real-life situations. The assumption is that this close relationship will reinforce the transfer of concepts and skills from the learning tool to real-life situations that call for numerate thinking.

Background information

In the Netherlands, many students' achievements in arithmetic and mathematics in the basic streams of pre-vocational (age 14-16) and vocational (age 16-19) education are unsatisfactory. These achievements are measured using pen-and-paper, and sometimes computer-aided, tests. Most of these students in the basic stream have a long history of being diagnosed as deficient, and of subsequently receiving remedial help, using pen-and-paper drill materials, until they show some progress on the test or until the school year ends.

In some schools it was noticed that in the basic stream of pre-vocational education the scores of the students in this kind of written test were roughly the same at the end of the second year as the scores at the end of the third year, and roughly the same as the scores at the end of the fourth year on the same tests. The mathematics courses and the remedial work do not seem to yield much added value. We have found the same situation in schools in the Netherlands as John Gillespie found in England and Wales:

> One response was to provide 'stand-alone' maths techniques courses, often outside specific vocational contexts. But many students saw such courses as not relevant to their main courses, and there was little evidence of their being able to transfer skills from them to their vocational work. (Gillespie, 2000, p.55)

We observed that in the mathematics classroom motivational problems outweigh any development of numerical skills and knowledge. Zevenbergen (2000) reports similar experiences:

> For many of the students for whom school mathematics has been a disempowering experience, a broader conceptualisation of mathematics may offer different experiences than the current regimes of school mathematics that are on offer in contemporary institutions. This may be particularly the case for those students undertaking vocational oriented courses where it is common for students to have low levels of numeracy and have been alienated from the formal schooling process. (Zevenbergen, 2000, p.222)

We also found a fair amount of math anxiety in many students (Tobias, 1994).

There are two contesting views in the Netherlands regarding the solution to this problem. One view states that more time must be spent on rigorously training the students in basic literacy and arithmetic in combination with practical vocational education. The other view claims that a paradigm shift to project-based authentic learning will bring an end to problems of motivation, and will create an environment for the successful acquisition of numeracy knowledge and skills. However, in this approach we find hardly any explicit definitions of numeracy, or clear images of how it would operate in classrooms.

A fruitful discussion of the fundamentals of numeracy (or mathematics or arithmetic) within these students' education is overshadowed by the clash of ideologies behind these two points of view. The discussions between the supporters of the different views are often quite intense and emotional. These kinds of discussions are reported from other countries as well, for instance Australia (Zevenbergen, 2004), (Fitzsimons, 2002) and the USA (Wilson, 2003), sometimes referred to as the 'Math War'.

Within this context we made the choice to first investigate more closely and in depth what individuals think when they are coping (or not coping!) in situations that call for numerate thinking. This has lead to the research question for the ongoing study: 'What is numerate thinking?'. That question is made more operational by means of the following question: 'How can the numerate thinking of individuals be identified, described, analyzed and understood?'

In this paper we limit ourselves to some broad outlines of methodology and results of this study, and focus more on the development of the design principles for the learning tools that are derived from this research.

Numeracy, being numerate, identifying numerate thinking

Definitions

In our study, we used as a starting point the definition of numeracy that is most widespread in the Netherlands:

> Gecijferdheid is de combinatie van kennis, vaardigheden en persoonlijke kwaliteiten die een individu nodig heeft om adequaat en autonoom om te gaan met de kwantitatieve kant van de wereld om ons heen. (www.gecijferdheid.nl, 2007), (Wiki-NL, Gecijferdheid, 2007),

which can be translated as:

> Numeracy is the combination of knowledge, skills and personal qualities that an individual needs to adequately and autonomously deal with the quantitative aspect of the world around us. (www.gecijferdheid.nl, 2007)

This is in fact more a definition of being numerate, as it suggests a certain level of action or thought. In this definition numeracy not only encompasses knowledge and skills, but also personal qualities such as self-confidence, perseverance, curiosity, a lack of fear of the quantitative, assertiveness, and so on. This combination of knowledge, skills and personal qualities is quite often referred to in the Netherlands as 'competence'. In that sense it is quite different from, for instance, a definition of competence as *the ability to do a particular activity to a prescribed standard*. (Working Group on Vocational Qualifications, 1986). This emphasis on the combination of attributes is also in line with the definition of numeracy situations by Gal (2000), who states that numerate behaviour is also enabled by dispositional elements such as prior beliefs, attitudes and habits.

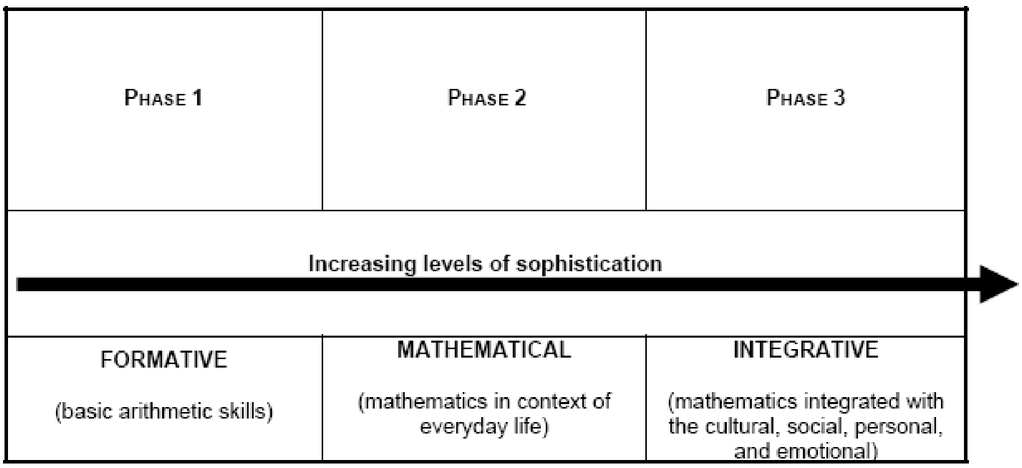
The verb 'to deal with' comes closest to the meaning of '*omgaan met*' in the Dutch definition. In this definition the focus is on identifying, interpreting, acting upon, and communicating about situations. In this sense it is close to the operational definition used by the Adult Literacy and Life Skills Survey (ALL). There the verb 'to manage' is used (Gal et al., 1999), (Groenestijn, 2000).

The adjective 'adequately' implies that the knowledge, skills and personal qualities must be effective, in the sense that the individual accomplishes something in a situation by using numerate thoughts or actions.

The adjective ‘autonomously’ gives some prescriptions for the way in which the success is accomplished: not by avoiding, not by asking someone else, but through the individual’s own thoughts and actions. It implies that individuals must rely on strategies that are at their own disposal to deal with specific situations. Avoidance strategies are among the most frequently used strategies of many individuals for coping with quantitative situations.

In a certain sense, this definition of numeracy is close to the idea of Wedege (2001) of a ‘*math containing everyday competence*’.

Adult Numeracy Concept Continuum of Development



A continuum of development of the concept of numeracy showing increased level of sophistication from left to right (from Maguire & O’Donoghue, 2002)

In the organisational framework of Maguire and O’Donoghue (2002, 2003) (figure 1) this definition fits into the integrative phase of the development of the conceptualisation of numeracy

Figure 1. Adult Numeracy Concept Continuum of Development

In the categories used by Jablonka (2003) this definition fits into the category of ‘mathematical literacy for evaluating mathematics’, which aims at interpreting information presented in a numerate way (Hoogland & Jablonka, 2003).

Numeracy incidents

From this definition we derived the concept of a ‘numeracy incident’. The quantitative aspect of the world around us takes many forms. It shows up in artefacts and devices (meters, gauges, clocks, numbers, symbols), in constructions (measurements, angles, spatial attributes) and in texts (numbers, symbols, diagrams, maps, graphs, formulas).

When individuals have to deal with these manifestations of the quantitative aspect of the world, there is a possibility that they will act or think numerately. If they do so in an identifiable way, we term this a numeracy incident. A numeracy incident is thus a situation plus an individual’s numerate response to that situation.

We make use of the underlying assumption that a situation in itself is not a numeracy situation. For example: if three persons are in a shop and have to choose between two differently sized and differently priced jars of jam, one person can make a choice after comparing prices and sizes. In this case, the situation plus the reaction of this person create a numeracy incident. Another person may make his or her choice based on the brand or the flavour of the jam. In this case, the situation and the reaction of this person do not create a numeracy incident. The third person may become very confused by all the numbers and prices on the jars, and simply picks up the first jar to end the confusion. In our study we also will call this a numeracy incident (although it might be better to call it a numeracy accident!).

Of course some situations are by their nature almost impossible to deal with without creating a numeracy incident: buying, selling, managing one's income, and so on. Systematically collecting numeracy incidents from interviews with students gave a good impression of these students' 'numeracy world', and a good starting point for the design principles of the learning tools.

Methodology

The research was conducted as follows. Over a period of two years, in three cycles, 9, 10 and 4 students respectively were interviewed on issues related to their daily life and work. We focused on students in the 15-19 age group in the basic stream of pre-vocational and vocational education. The length of the interviews, and of the videotapes that were analyzed, was on average 8.6 minutes. An instrument was developed to identify and categorise the numeracy incidents as they showed up or were referred to in the interviews. In the course of the cycles the instrument was refined and the interviewing technique improved.

In the first cycle the students were interviewed about lifestyle issues, from which we assumed they would generate numeracy incidents. Those lifestyle issues were: hobbies, clothes, part-time jobs, holidays and travel, future jobs, savings and allowances, and mobile phones. The interviews were simple one-on-one talks about the topics.

In the second and third cycles the students were interviewed about products they had made in the job-oriented parts of their study. In these, they design and construct products in a way that is closely related to their future jobs. For example, they constructed a bicycle trailer for a surfboard, garden lights for a company, spotlights for the school, waste bins for the school shop, tomato soup for the school lunch, a rectangular flower bed, and so on. After finishing or almost finishing their products, they were asked to come and say something about the way they had designed and manufactured the product. The product was always at hand.

The assumption was that both interview topics – lifestyle issues and job-oriented tasks – would be a rich source of numeracy incidents. From the results it was clear that this assumption held true (Hoogland, 2005).

These interviews with the product at hand are a variation on Stimulated Recall. This technique is used by various researchers in the field of mathematics education (Zevenbergen, 2000, 2004), (Lyle, 2003), and was used extensively in second language learning research (Gass, 2000). In stimulated recall, one looks back with the respondent to earlier events, and tries to construct the respondent's thinking. This recall is stimulated by showing photos, films or artefacts. This kind of retrospective reporting is used to explore learners' thought processes (or strategies) at the time of an activity or task.

The instrument

The instrument was refined in the course of the cycles. The first version of the instrument simply consisted of the 'big ideas' from the PISA Framework: Quantity and Number Sense, Shape and Space, Change and Relationship, and Data Analysis. We wanted to see if these categories were sufficient to identify numeracy incidents, which was indeed the case. In the first nine interviews, with an average length of 8 minutes, an average of 15 numeracy incidents could be identified.

Some examples are:

- It costs me 22 Euros 50 a month. No, not 42, 22. 42 would be weird. In the old days you could get that kind of contract for 45 Guilders. Now it's 22 Euros. And then you'd be better off using prepay.
- I get 3 Euros an hour. A regular Tuesday evening, 3 hours babysitting, and sometimes in the weekend.
- It's a three-day trip to Morocco. I don't know how many kilometres it is.
- About 100 texts. That's 22 Euros, that's 22 cents a text.

The instrument was refined in the course of the cycles to include more relevant categories for distinguishing the numeracy incidents. The instrument currently contains items such as:

- Knowledge Concepts
  - Magnitude sense - societal
  - Magnitude *sense* - physical
  - Magnitude sense - individual
  - Relational sense
  - Chance sense
- Skills
  - Reasoning
  - Doing arithmetic

- (Negative) Dispositions
    - Avoidance – short yes/no
    - Avoidance – changing the subject
    - Avoidance – socially desirable answer

A chart showing these categories is given in the appendix to this paper.

The interview technique

The interview techniques were also improved in the course of the cycles.

Before the first cycle, the interviewing instruction was that deepening or elaborating questions were to be asked as soon as numerate thinking showed up in the answers of the respondents. Another interview instruction was to avoid direct questions about the transfer of the mathematical concepts or skills. From earlier experience it was already known that asking such questions would provoke anxiety, avoidance or 'desirable' answers. Despite this instruction, the interviewers were not able to completely avoid such questions or this topic, so clear signs of these emotions, and corresponding actions, were to be seen in the results.

In analyzing the tapes we also noticed a remarkable difference between '*interviewing* a student about lifestyle issues or the product and their way of working' and '*letting them talk* about their product and way of working'. Some examples of interview questions are:

- Do you have a contract for your mobile phone or a prepay card, and why?
- How much do you earn on average with your part-time job?
- Do you have a savings account, and how do you use it?

In the first case these students tend to give very short answers, preferably yes or no. And in many instances, noticeable by the accompanying hesitations, they try to give the 'right' answers: i.e. answers given in a questioning way, accompanied by a questioning look.

Some examples of letting them talk are asking:

- I saw you made this product. It's a very nice piece of work. Can you tell me something about it? How did you make it?
- You've got a mobile phone. I'm curious. How does that work out with the costs?

In this way most respondents usually get into a flow of talking more easily and enthusiastically about their issues, their products and their way of working. The role of the interviewer was merely to give some non-interventional incentives to continue talking.

We learned in our research that this second technique revealed more numeracy incidents, showed more clearly how the students were thinking numerately, and provided the best opportunities for gaining answers to our research question.

Of course this could present an interesting paradox for numeracy education. Could it be more effective not to talk about numeracy? Or at least not noticeably?

Results

We will limit ourselves to the results that were relevant to arriving at the design principles for the learning tools. We found as our main results:

- When the artefact or device is at hand the students are involved in considerably more numeracy incidents than when the artefact is not at hand.

- When the artefact or device is at hand the students show more usage of gestures to support their numerate thinking than when the artefact or device is not at hand.

- The students use everyday language to describe mathematical concepts. They use quite a lot of non-distinct descriptions: 'what-d'you-call-it', 'something-like-that'. These non-distinct descriptions are much more prevalent than the use of mathematical language that could be relevant in the situation.

- Relevant technical language is used quite regularly; much more regularly than the use of relevant mathematical language.

Some examples

A student has constructed a window casing and is talking about it. An angle of 45 degrees was necessary in a certain part of the casing. The student uses technical construction words such as '*overlengte*' (excess length), '*schrijfhaak'* (set square) and '*afschrijven'* (marking out) without hesitation. When it comes to creating the angle of 45 degrees the language becomes much less defined and the number of supporting gestures rises.
Interviewer*: What about those 45 degrees?*
Student*: It's something like this (gestures), then it goes like that (gestures), then there's an angle with your set square, you can shift it a bit and then it's exactly 45 degrees.*
Nevertheless, it is clear from the video clip that the student knows what he is doing and knows how to construct the 45-degree angle.

A student has constructed a plan for a L-shaped flowerbed with outside measurements of 150 x 150 cm and a width of 60 cm. He shows an ingenious way of constructing the plan, which is also very effective as a working plan for the actual construction.
Interviewer: *How long are those inside measurements now?*
Of course the inside measurements are 90 x 90 cm. The student also used this in his construction.
Student: *I dunno, I'm not much of a numbers man.*

A student has constructed a pyramid shaped garden lamp together with his team. The top of the lamp consists of a triangle that bends into two sides of the pyramid, and a triangle that makes the lampshade complete. The student shows by bending a triangular

piece of paper that the last triangle always fits. This demonstration reveals his numerate thinking. The language supporting the demonstration is very nondescript.
Student: *It always fits, a little one, a pointed one, it just fits, and a (mumbling), it just fits, the other just bends.*

Conclusions

We draw the following conclusions from the results.

- The quality of the numeracy incidents is much higher for the students when they have an artefact or device at hand than when the product is not available.

- Respondents use gestures to support their numerate thinking. They use them more when a product is at hand.

These two conclusions are very important in combination. Without the artefact or device there is hardly any opportunity for gesture, and for these students that means that their opportunity to show their numerate thinking is very limited. These conclusions offer also a possible explanation for why these students score so poorly on written tests. Showing their numeracy thinking in writing only is a very limiting setting for these students.

- Students use a very limited mathematical vocabulary in numeracy incidents.

- Students regularly use technical language in numeracy incidents.

These two conclusions indicate that the relevant technical language is meaningful for the students: it is internalised. Hardly any mathematical language seems to be internalised by these students. Mathematical language does not seem to be the key tool for showing their numerate thinking.

Towards a multimedia tool for numeracy

Based on the research described, we are in the process of developing web-based multimedia learning tools which deal with the basics in arithmetic, and some numeracy concepts such as the meaning of numbers, interpreting and deciding, division and dividing, area and volume, percentages and ratios.

The design principles for the learning tools were derived from this research. These design principles are:

- Every problem posed must be directly related to a real situation, presented in photos or short video clips. Situations and contexts are not presented completely or mainly in text.

- Necessary information on the situation is presented in written and spoken (voiceover) text.

- Every question posed on the situation must be able to be conceived of by the student as a real and relevant question.

- Answering the questions posed demands some numerate thinking.

- The build-up is in the complexity of the situations and not in the complexity of the mathematical concepts.

On the basis of these design principles, the tools were developed in the spring of 2007. The first trials were conducted with three groups of students. The results are currently under investigation.

References

American Institutes for Research (2006). A Review of the Literature in Adult Numeracy: Research and Conceptual Issues. USA, Washington DC: IAR

FitzSimons, G.E. (2002). What Counts as Mathematics? Technologies of Power in Adult and Vocational Education. Dordrecht: Kluwer Academic Publishers.

Gal, I., M. van Groenestijn, M. Manly, M-J. Schmitt, D. Tout (1999). Numeracy framework for the international Adult Literacy and Life Skills Survey (ALL) ttp://nces.ed.gov/surveys/all

Gal, I. (Ed.) (2000). Adult Numeracy Development: Theory, Research, Practice. Cresskill, NJ: Hampton Press.

Gass, S.M. (2000). Stimulated recall methodology in second language research. Mahwah: Lawrence Erlbaum Associates, Inc.

Gillespie, J. (2000). The Integration of Mathematics into Vocational Courses. In: Bessot, A. & Ridgway, J. (Eds.): Education for Mathematics in the Workplace. (pp. 53 - 64). Dordrecht: Kluwer Academic Publishers

Groenestijn M. van (2002). A Gateway to Numeracy. The Netherlands, Utrecht: CD B press, University Utrecht

Hoogland, K. & Jablonka, E. (2003) Wiskundige geletterdheid en gecijferdheid. In: Nieuwe Wiskrant. Tijdschrift voor Nederlands Wiskundeonderwijs, 23(1) , (pp. 31-37). Utrecht: Freudenthal Instituut. [Mathematical Literacy and Numeracy. English translation at www.gecijferdheid.nl]

Hoogland, K. (2005). Hoe gecijferd is een basisberoepsgerichte leerling in het VMBO?. In: Goris, T. & Wesker, L. (Eds.), Nieuwe Wiskrant. Tijdschrift voor Nederlands Wiskundeonderwijs, 24(3), (pp. 36-39). Utrecht: Freudenthal Instituut. [How numerate is a student in the basic stream of pre-voctional education. English translation at www.gecijferdheid.nl]

Jablonka, Eva (2003). Mathematical Literacy. In A.J. Bishop, M.A.Clements, C. Keitel, J. Kilpatrick, F.K.S. Leung (Eds.). Second International Handbook of Mathematics Education (pp. 75-102). Dordrecht: Kluwer Academic Publishers,

Lyle, J. (2003). Stimulated Recall: a report on its use in naturalistic research. In: British Educational Research Journal 29 (6) (pp. 861-878).

Maguire, T., & O'Donoghue, J. (2002). A grounded approach to practitioner training in Ireland: Some findings from a national survey of practitioners in Adult Basic Education. In L. Ø.Johansen & T. Wedege (Eds.), Numeracy for empowerment and democracy? Proceedings of the 8th International Conference of Adult Learning Mathematics - A Research Forum (ALM8). Danmark, Roskilde: Roskilde University, Centre for Research in Learning Mathematics.

Maguire, T., & O'Donoghue, J. (2003). Numeracy concept sophistication - an organizing framework, a useful thinking tool. In J. Maaß & W. Schlöglmann (Eds.), Learning mathematics to live and work in our world. ALM-10. Proceedings of the 10th international conference on Adults Learning Mathematics in Strobl (Austria) Austria, Linz: Johannes Kepler Universität Linz.

Tobias, S. (1994). Overcoming Math Anxiety. New York: Norton, W. W. & Company, Inc

Wilson. S.M. (2003). California Dreaming, Reforming Mathematics Education. New Haven and London, Yale University Press

Zevenbergen R. (2000). Ethnography and the situatedness of workplace numeracy. In: Bessot, A. & Ridgway, J. (Eds.): Education for Mathematics in the Workplace. (pp 208 - 224) . Dordrecht: Kluwer Academic Publishers

Zevenbergen R. & Zevenbergen K. (2004). The Numeracies of Boat Building. Paper presented at ICME 10, Copenhagen.

Appendix A

Categories chart for numeracy incidents

Knowledge Concepts	Transcription	Description of supporting gesture
Magnitude sense - societal		
Magnitude sense - physical		
Magnitude sense - individual		
Relational sense		
Chance sense		

NB. Not knowing something is also a numeracy incident.

Some examples:

Magnitude sense – societal: hourly wages, price of prepay telephone cards, usage and price of petrol

Magnitude sense – physical: dimensions and distances, height of a door, distance between countries, distance between cities, speed of walking

Magnitude sense – individual: wages for your job, your monthly allowance

Skills	Transcription	Description of supporting gesture
Reasoning		
Doing arithmetic		

(Negative) Dispositions	Transcription	Description of supporting gesture
Avoidance – short yes/no		
Avoidance – changing the subject		
Avoidance – socially desirable answer		

Some examples:

Avoidance – short yes/no: the answer is immediate, expression becomes blank
Avoidance – changing the subject: answering a slightly different, non-numerical question
Avoidance – socially desirable answer: repeating something heard, language becomes more serious