A framework for mathematical literacy in competence – based secondary vocational education

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Abstract In competence-based vocational education there is a risk that mathematics becomes invisible and unassessed, with deteriorating mathematical skills as a consequence. This is what happened in the Netherlands. To reverse this trend we developed a framework of reference for mathematical literacy in secondary vocational education (MBO) with which domains and levels of mathematical literacy required in all MBO occupations could be identified. This chapter focuses on the lessons that we learned from the process of developing the framework with all relevant stakeholders, and from how it was used by the Centres of Expertise. In order to generalize our experiences we formulate criteria that such a framework should fulfil in order to be a useful interface between representatives of school mathematics and of services and industry.

Introduction

The position of mathematics in vocational curricula is the topic of a long-standing debate, especially in countries that move towards more competence-based vocational education (CBVE). In CBVE the structure with vocational and general subjects with attainment targets (including targets for mathematics) is substituted by a qualification structure based on general and vocational competencies. Despite potential advantages of CBVE such as higher student motivation (Van den Berg & De Bruijn, 2009), there can be major consequences regarding the visibility and accountability of mathematics in vocational curricula. Visibility here refers to how explicitly mathematics is mentioned in qualification files and therefore how visibly it ends up in curricular materials. Accountability refers to the responsibility stakeholders feel to assess students' mathematical knowledge and to pay attention to mathematical literacy as part of competence-based projects or apprenticeships.

In the Netherlands, the introduction of CBVE has led to a situation in which mathematical knowledge and skills are still required as part of occupational core tasks and work processes, but in the qualification files that describe the competencies a person needs to fulfill a job or function, hardly any explicit reference is made to the mathematics (or any other discipline) involved. This had a major impact on the visibility and accountability of the mathematics required in the 241 occupations that the Dutch senior secondary vocational education system prepares for. For some programmes (e.g. educational and nursing assistants) this has led to worrying situations and political uproar (Bronneman-Helmers, 2006).

To improve the visibility and accountability of mathematics in vocational education, several Dutch institutions concerned with mathematics education and vocational education collaborated in developing a national framework for mathematical literacy in secondary vocational education (in the following we use the Dutch abbreviation MBO). The framework is modelled after the Common European Framework of Reference for Languages (CEFR, 2004) because it is widely used in Europe to identify and prescribe the standards of language fluency for different vocational qualifications, because it supported the visibility and accountability of language requirements in Dutch vocational education, and because many Dutch teachers know this framework.

The main challenge was to develop a framework that could be used in a variety of communities such as schools, companies and national Centres of Expertise for Vocational Education, Training and the Labour Market (in the following just 'Centres of Expertise') and that would allow mathematics teachers, teachers of vocational subjects and professionals to communicate about the domains and levels of mathematical literacy required. Mathematical literacy is defined in the OECD Programme for International Student Assessment PISA as: "an individual's capacity to identify and understand the role that mathematics plays in the world, to make well-founded judgements and to use and engage with mathematics in ways that meet the needs of that individual's life as a constructive, concerned and reflective citizen." (OECD, 2003, p.15). The aim of this chapter is to draw lessons from our experiences in such a way that readers from other settings can learn from them. In particular the central question addressed in this chapter is: *What criteria should a framework of reference for mathematical literacy meet, in order to make mathematics in competence-based vocational education visible and accountable?*

Answering this question requires some background on the specific features of the Dutch educational system. Next we describe criteria for the framework for mathematical literacy in MBO and discuss to what extent the framework has indeed contributed to the visibility and accountability of mathematics in MBO. Finally we formulate more general lessons learned from the design and implementation of the framework.

Background information about the Dutch vocational system

About 40% of the Dutch 12-year-old pupils attend general secondary education (pre- university track or general education track). The remaining 60% attend VMBO — pre- vocational secondary education; such early pre-selection is unique in the world. A large percentage of the VMBO students, when 16 years old, move up to MBO. A minority of students move from general secondary education into MBO (see Figure 1). A small percentage of MBO students — only from level 4 — continue their studies in higher professional education (HBO). With 480,000 students in regular MBO and 26,300 in Agriculture/Green, MBO is the largest and most diverse sector of Dutch senior secondary education. It provides both theoretical instruction and practical training in preparation for the practice of a wide range of occupations for which a vocational qualification is necessary or useful. Its main target group is young people from the age of 16 (average age 18.5). There are four sectors:

- economics and business (e.g. sales agents, salary administrators, secretaries);
- engineering and technology (e.g., bricklayers, car mechanics, electricians);
- agriculture and food technology (e.g., florists);
- health care, social care, welfare and sports (e.g. hairdressers, nursing assistants).

MBO is provided at four qualification levels:

level 1: assistant training;

level 2: basic vocational training;

level 3: professional training;

level 4: middle-management training and specialist training.

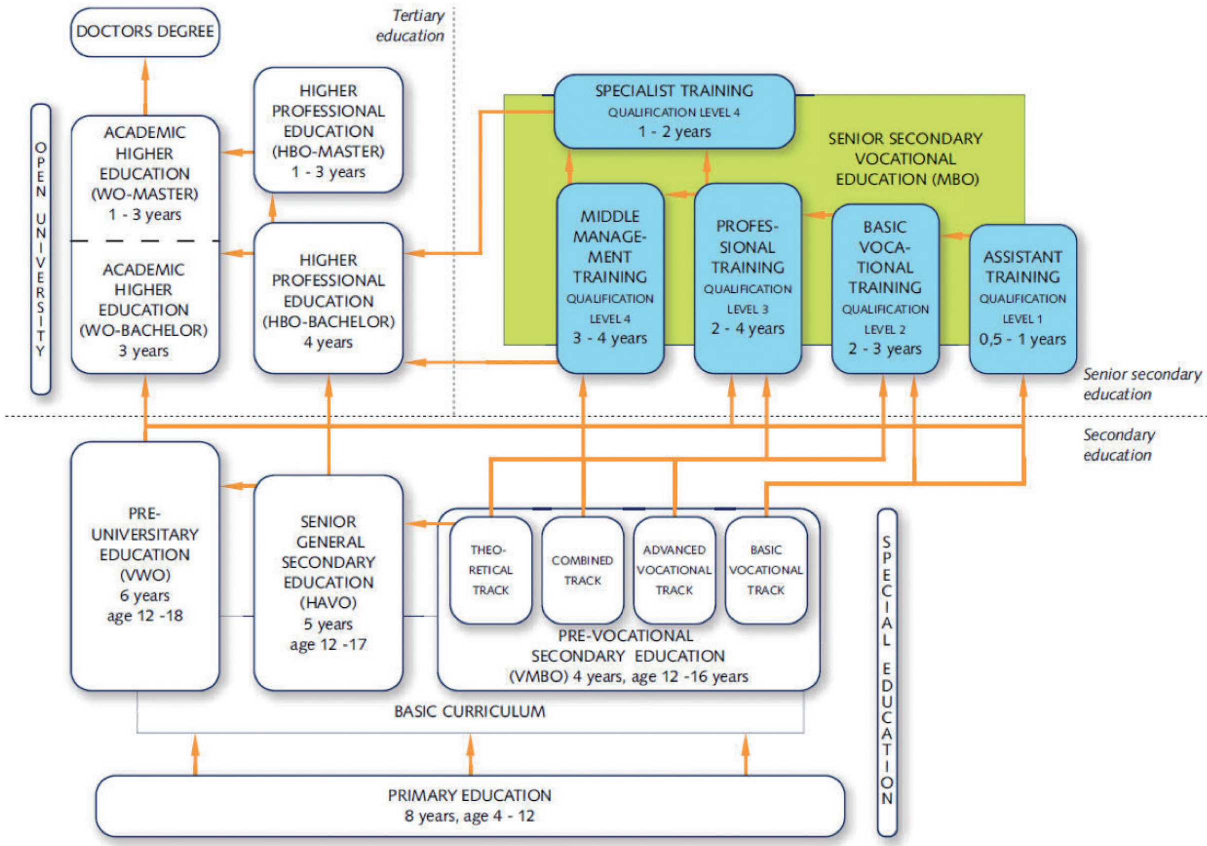

Figure 1—Dutch educational system (MBO is highlighted)

There are two learning pathways: vocational training (BOL) where practical training takes up between 20% and 60% of the course; and block or day release (BBL) where practical training takes up more than 60% of the course (formerly the apprenticeship system).

The competencies required for starting professionals are laid down in qualification files, which are produced by the 18 national Centres of Expertise. A qualification file can include several occupational profiles on the same or different levels; these profiles are variants of the main occupation (e.g., service engineers who concentrate on washing machines, central heating, air conditioning etc.). Once approved by the Ministry of Education, these qualification files have a legal status. Based on the qualification files, each school is expected to design appropriate educational programmes. Thus put simply, Expertise Centres determine the 'what' and schools the 'how'. Apart from the requirements for the starting professional as described in the qualification files and in the source document for 'learning, career and citizenship', there are no other curricular requirements. School are free to make their own decisions, as long as they can account for them.

The previous qualification system provided lists of attainment targets for all subjects including mathematics (if required). In technical programmes this included a list of about

50 mathematical concepts and skills, but many students and teachers often did not see the relevance of many of these targets. The current qualification files summarise the vocational core tasks and work processes but pay little attention to the underlying knowledge and skills: In the qualification files it is very common to read just very general requirements such as 'basic mathematics' in the column of knowledge required for specific work processes. The effect in many schools was that the teaching of mathematics was reduced considerably – the idea being that students would learn the mathematics needed in competence-based projects. However, companies, teachers and students increasingly complained that students learned too little about mathematics (and the languages). Stakeholders therefore agreed that the domains and levels of mathematical literacy required for core tasks and work processes should be formulated more explicitly in the qualification files. For this purpose we developed a framework that we characterise in the next section in terms of the criteria it had to meet.

Criteria for a framework for mathematical literacy in CBVE

The framework for mathematical literacy had to provide the relevant actors in the MBO community with an instrument that met the following criteria:

CRITERION 1: it has to facilitate communication about role and place of mathematics in vocational education in general.

CRITERION 2: it has to allow stakeholders who are not educated as mathematics teachers to identify the domains and levels of mathematical literacy required for each specific occupation.

In order to meet these criteria it seemed wise to focus on two additional criteria:

CRITERION 3: create common ground and support for mutual understanding.

CRITERION 4: align the framework with existing instruments that MBO stakeholders know.

In the remainder of this section we describe how we tried to meet these criteria.

In terms of criterion 3, we (Freudenthal Institute of Science and Mathematics education, Fi) decided to involve all relevant stakeholders: the association of VET Colleges (MBO-raad), the sector organisation for AOCs (AOC-raad), the association of centres of expertise (Colo), the process management of CBVET (MBO 2010), the national organisation for curriculum development (SLO), the research and consultant agency for VET (Cinop), the teacher education department of the university of applied sciences Utrecht (HU). The actual development of the framework was led by the Freudenthal Institute and carried out with help of Cinop,

	Number, quantity, measure	Space and shape	Data handling and uncertainty	Relations, change and formulas
Z2	s capable of mathematically modeling, at a professional level, a practical or theoretical problem situation in the area of numbers, amounts and measures, of judging the validity of the model and analyzing the problem within that model, of generating solutions and reflecting critically on them	Has an understanding of advanced mathematical methods in geometry, for instance from analytical geometry and linear algebra, can apply these at a professional level for modeling a geometrical problem situation and can use them to analyze the situation and reflect critically on the whole of model an	Can independently set up a statistical study at a professional level and analyze data using advanced techniques and draw sound conclusions from that analysis.	Is capable of using, at a professional level, advanced mathematical instruments in the area of relations and changes to independently model and solve complex problem in the personal/public domain and in the workplace.
Z1	Uses numbers, amounts and measures in complex, non-standard situations, can work with a mathematical model of the situation and adapt it if necessary, is capable of developing procedures to reach a solution to a problem.	Interprets and analyses complex situations in 2D and 3D using geometrical concepts, properties and techniques. Can set up a mathematical (geometrical) model of the situation and calculate, construct and reason within that model to solve a complex problem.	Collects, combines, interprets and analyses data, including in very complex situations, while utilizing statistical methods and models. Can formulate a (mathematical) of the situation and calculate and reason within that model to solve a complex problem from daily life, the workplace or education.	Is capable of typifying, analyzing and describing connections and changes in complex, non-standard situation, using mathematical symbols, notations and concepts.
Y2	Uses numbers, amounts, measures and efficient procedures in somewhat complex and new situations, and can, if necessary, let go the relation to the situation and use a mathematical model of the situation.	Reasons and calculates with the aid of geometrical concepts, properties and techniques in 2D and 3D, and can, if necessary, let go the relation to the context and work with a mathematical model of the situation at a more abstract level.	Collects and processes data, also in new and unique situations, through using statistical methods. Combines and analyses complex (numerical) information from various sources, can let go the relation to the concrete situation.	Recognizes, interprets and uses connections in complex situations; can analyze and combine different representations of a relation, using mathematical symbols, notations and concepts, and is capable of developing a strategy to solve a practical problem and can, if necessary, let go the relation to t

Figure 2—Summary of the Dutch framework of mathematics (Wijers et al, 2009).

HU and SLO. The other parties functioned as a soundboard. We also organised six pilots on MBO schools to check the 'workability' of the framework (under construction) in practice. In two sessions within each pilot, teachers and coordinators experimented in using the framework to set up a plan for their schools on how to organize the teaching and learning of mathematical literacy. Finally we organised sessions to support the Centres of Expertise in identifying the mathematics in the core tasks and works processes, and to reference the content and level in terms of the framework. These sessions were followed up by continuous support provided by the designers through email, phone or direct contact.

	Number, quantity, measure	Space and shape	Data handling and uncertainty	Relations, change and formulas
Y1	Uses numbers, amounts and measures, and applies familiar procedures and argumentations in simple non-standard situations, is capable of interpreting the results and reporting on them.	Understands and uses geometrical concepts and techniques to create images and constructions in more complex situations, and to calculate and reason with shapes and situations in 2D and 3D.	Interprets and combines (numerical) data from different charts and diagrams, collects numerical data, summarizes the data and can represent it in various way in diagrams or numbers, following known procedures.	Recognizes, interprets and uses connections and relations in somewhat complex (including unfamiliar) situations, can describe a relation between quantities for a concrete task in chart, graph and (word) equation, and can apply known standard procedures in an argued and reasoned manner.
X2	Uses numbers, amounts and measures, performs familiar calculation and measuring tasks in concrete, somewhat complex but orderly situations and can interpret the results.	Understands and uses common geometrical concepts surrounding orientation; understands and uses geometrical concepts and simple prescribed techniques to describe and construct shapes, figures and orderly situations in 2D and 3D.	Reads information from charts, schemes and diagrams, and collects simple numerical data, can represent this in an understandable way, for concrete tasks in familiar situations with little complexity in the personal/ public domain and in the workplace.	Recognizes and uses regularity, patterns and simple connections in familiar situations with little complexity, can compare representations (text, chart, graph, rule of thumb) with each other in simple situations and can do calculations based on simple rules of thumb for concrete tasks.
X1	Uses numbers, amounts and measures, performs simple calculations and measuring tasks in concrete, unequivocal and familiar situations	Reads and understands everyday geometrical concepts on orientation, shapes, figures and situations (2D and 3D) for concrete tasks in unequivocal and familiar situations.	Reads information from simple charts, schemes and diagrams for concrete, explicit tasks in familiar situations with little complexity, will know in this sort of situation whether something is a case of coincidence and uncertainty (chance).	Notices, understands and uses regularity, patterns and relations (connections) in concrete, unequivocal and familiar situations where numbers or quantities are represented in text, chart or graph.

Figure 2—*(Cont.)*

In terms of criterion 4, the institutions involved decided the framework should have a structure similar to the CEFR for the languages, which is widely used in MBO. Instead of the six levels *A1*, *A2*, *B1*, *B2*, *C1* and *C2* of the CEFR, we used the labels *X1*, *X2*, *Y1*, *Y2*, *Z1* and *Z2* were used to avoid confusion and conflation of the two frameworks. We also wanted to avoid that levels of the CEFR would be used for mathematics because a profession might require high language skills but low mathematical ones (receptionist), or vice versa (construction worker). Figure 2 shows the basic structure of the resulting framework for mathematical literacy.

In terms of criteria 1 and 2 we discuss below how we formulated the content domains and levels so as to ensure that all stakeholders could work with it.

Content domains

Formulations in the framework had to be recognizable to mathematical experts but be not so mathematical that they would lead professionals astray. To elaborate on this point we need to address briefly the nature of workplace mathematics. Steen (2003, p. 4) has succinctly characterised it as follows: “Mathematics in the workplace makes sophisticated use of elementary mathematics rather than, as in the classroom, elementary use of sophisticated mathematics.”

From research in workplaces (Hoyles et al., 2002) and our own experiences, we knew that many employees and even employers think they do not use mathematics apart from basic arithmetic, whereas mathematics educators tend to have a much more liberal and comprehensive view on what counts as mathematical. Hence, using terms such as geometry, statistics or algebra might hinder the communication with companies and also with teachers of occupational subjects. On the other hand, mathematicians and mathematics educators still need to be able to identify the mathematical areas to be drawn from in the professions. We analysed existing frameworks for mathematical literacy in various settings: the PISA 2003 assessment framework (OECD, 2003), the numeracy framework for the international Adult Literacy and Life skills Survey (Gal, et al, 1999), Numeracy in the Scottish Core Skills Framework (2003), Equipped for the Future Content Standards (Stein, 2000), Functional Skills Standards for Mathematics (2007) and the Canadian Essential Skills Research Project, which connects mathematics to occupations on a detailed level. Based on the commonalities we found in these frameworks, we decided on having four domains in our framework that would cover basic numeracy (on the lower levels) as well as formal mathematics on a higher level of abstraction (on the higher levels in the framework). We settled on the following domain names: Number, quantity and measurement; Space & shape; Data handling & uncertainty; Relations, change & formulas.

Levels

A next challenge was to decide what adds to the level of mathematical knowledge required. When we distil the mathematics used in concrete situations, it often does not seem to be much more than using basic operations of addition, subtraction, multiplication and division. However, as Kent et al. (2007, p. 79) observed

> The mathematics involved in finance seems superficially similar to what appears in the secondary school mathematics curriculum (for example, calculating compound interest). Yet the effect of the workplace context is to introduce a significant degree of complexity to even the simplest mathematics. No mathematical procedure is an isolated exercise; it is part of a set of decisions and judgments that have to be made about what is a complex process or product. In Lifetime Pensions, the actuarial assistant phrased it thus: "The maths involved is not hard, but it is applied in a very complicated way—there are the company rules and Inland Revenue [tax] rules."

Based on the more general observation that there is an intricate relationship between mathematical and vocational knowledge we decided that contextual reasons should be taken into account when deciding on the level of the use of mathematical knowledge required. For example, a pharmaceutical assistant uses rather basic arithmetic including proportion and percentage when preparing drugs, but she cannot afford a single mistake. Hence the level of mathematical fluency in the realm of Number and Quantity has to be high (e.g., Y2) despite the fact that her calculations without context might seem rather basic. As the reader has seen in Figure 2 we settled on general formulations in the 'can do'- statements, that refer to the importance, complexity, or uniqueness of situations in which mathematical knowledge and skills are used. To formulate this growing complexity between levels we used factors also addressed in the adult numeracy framework of the IALS (Gal et al. 1999). Since MBO level 4 programmes prepare students for higher professional education (HBO), we wanted the framework to apply to mathematical literacy in higher education as well. In analogy to the CEFR we therefore reserved the highest level Z2 for mathematical literacy on a professional level.

Detailed descriptions

What is typical for mathematics in occupations and therefore in vocational education is its contextual character. The framework needed to reflect this, both in the formulation of skills as well as by the use of authentic examples from vocational contexts. These contextual examples help the users of the framework to identify the mathematics that is already implicit in the core tasks and work processes in the qualification files, but so far had remained hidden and had never been emphasized.

The functional use of mathematics was stressed in the framework by taking care that always the situation in which the mathematics is used is indicated in the 'can do' statement. When one clicks on a cell on the Dutch website of the Framework the 'can do'-statement is elaborated and illustrated using a fixed format consisting of: a set of sub skills; exam-

Description – number, quantity, measurement – Y1

Skill—Uses numbers, quantities and measures, and applies familiar procedures and arguments in complex and simple non-standard situations, is able to interpret the results and report on them.

Set of sub skills

- Applies (familiar) mathematical procedures in complex and simple non-standard situations to solve a problem or achieve a desired outcome, can do this through estimation, mental calculation, on paper or using a calculator.
- Reads (unfamiliar) measuring instruments, is capable of skillful interpolation, uses the system of measure units and can convert measures within the system (for example, convert 0,5 dl to 50 ml in a recipe).
- Is able to work with ease with decimal numbers, percentages and related fractions and measures that occur in familiar situations (for example, calculating VAT), while making use of their mutual relations
- Is able to verify whether the result of a calculation is in the right order of magnitude and what the 'margin for error' is.
- Is able to present calculations and their results in a clear and structured manner.

Examples/situations

- Procedure to calculate/formulate VAT
- Being treasurer for one's own (small) sports club without subsidies
- Calculate the amount of material for an order or assignment and bring enough materials
- Use percentage as a factor in depreciation and compound interest
- Determine extra costs for a non-standard repair on a car
- Give advice on the use of fertilizer
- Make, control and follow a budget for the cost of repairing defects and/or damage, and the cost of maintenance work
- Calculate a patient's liquid balance

Underlying mathematics

- Arithmetical procedures
- Decimal numbers, percentages, relations and fractions
- Measures and units

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Figure 3—The description behind the general statement of a Y1 cell of the framework

ples from citizenship and professions; and — in general terms — the mathematical 'background' (see Figure 3).

The large set of examples from various occupations should assist Centres of Expertise and teachers in deciding on the levels required and achieved. The mathematical background is there to facilitate communication with the mathematics community and to make it possible to refer to mathematical standards and curriculum documents.

	Number, Quantity, Measurement	Space and Shape	Data Handling and Uncertainty	Relationships, Change, Formulas
Y2				
Y1	✓	✓	✓	
X2	✓	✓	✓	✓
X1	✓	✓	✓	✓

Figure 4—Mathematical level for the cobbler, level 4

Space & shape	Y1	The traditional cobbler uses mathematical concepts and techniques to make illustrations and constructions, and to calculate and reason about shapes and situation in two and three dimensions. He uses the skills for instance in: • reading working plans and sketches • experimenting with shapes • making construction drawings • biomechanics • copy techniques • making detailed patterns • copying patterns on to material

Figure 5—The justification for the level Y1 on Space and Shape for the cobbler

Has the mathematical literacy required become more visible and accountable?

Visibility

The mathematics required in the occupations has indeed become more visible in the qualification files. The eighteen Centers of Expertise inserted the levels of required mathematical literacy into the 241 qualification files for 2009/2010 in the form of a matrix as shown in Figure 4. They did this for 614 out of the 642 occupational profiles.

About two thirds of the Centers of Expertise also provided a justification of the levels of mathematical literacy. These justifications give insight into the relationships between the mathematical skills and the core tasks and work processes of the occupational profile as can be seen in Figure 5.

The occupational work processes for which the cobbler needs a certain mathematical skill are listed with this skill. An interesting detail is the fact that in the text describing the skill in general terms, the cobbler is added as the acting person. In this way not only the content and level of the required mathematical literacy is made visible but also how and where it is used. This on its turn informs education. We also analysed a sample of the justified profiles and found a high degree of consistency across the Centres of Expertise in the way similar levels were attributed to similar core tasks. We take this as an indication that we succeeded in designing the framework as an instrument facilitating communication (criterion 1) and allowing non-mathematical stakeholders to identify the domains and levels of mathematical literacy required for specific occupations in a reliable way (criterion 2).

Accountability

We hoped that increased visibility of mathematical literacy in the qualification files would lead to more explicit attention in day-to-day education as well as in assessment in relation to students' future occupations. However, the Ministry of Education decided to introduce central examinations for mathematics (arithmetic), a measure that the majority of the MBO stakeholders consider to be at odds with CBVE. Because there is only one national exam per level for all MBO students, it is impossible to have connections to the specific occupations or even to the sectors of MBO. In sum, this means that the accountability for mathematics in MBO has increased but not in the way that the framework intended, i.e. taking account of the specificities of the different occupational. Instead there is a risk that mathematics again, like in previous times, will be taught and assessed as a separate subject with no clear relevance for the occupations.

Lessons learned

The framework proved a useful instrument in CBVE and served as an interface between various communities. In that sense the framework can be seen as 'boundary object' (Star & Griesemer, 1989), an artefact that is used in different communities and serves the communicative purpose of each of them. What turned out crucial was the set of clear examples from work situations. They function as 'two-sided' objects that have two faces at the same time: a mathematical one and an vocational one, which helped recognition by the various types of communities involved.

It is perhaps tempting to focus on characteristics of the framework itself, but the communicative processes supporting the use of such a framework are also very important. The support by designers was of critical value so as to help non-mathematical people from the Cen-

	Number , Quantity, Measurement	Space and Shape	Data Handling and Uncertainty	Relationships, Change, Formulas
Y2	22	14	13	12
Y1	153	78	149	72
X2	17	68	25	80
X1	2	17	1	7
blank	—	17	6	23

Figure 6—Levels per content domain of 194 mathematical profiles summarised

tres of Expertise in judging and valuing the content and especially the levels of the mathematics they had identified in the qualification files. Because the first author functioned as the main resource consistency across different parties was ensured.

The matrices with the levels for mathematical literacy we collected from all qualification profiles allowed us to make comparisons across them. Figure 6 gives a sense of the distribution of levels identified for 194 profiles on level 4. The Z-levels were never used, but might become relevant to higher professional education (HBO).

The marked cells indicate the levels occurring most frequently in the corresponding content domain. For the majority of these intermediate-level occupations a typical level on Number, Quantity and Measurement as well as on Data Handling and Uncertainty is required, whereas these occupations differ in the level of mathematics needed for Space and Shape and Relationships, Change and Formulas. It thus seems that the levels of mathematical literacy required for the first and third domain are rather generic, and that the levels of the second and fourth domains are more specifically connected to certain occupations. This raises questions about the focus in general secondary and pre-vocational education, in which the emphasis is on the second and fourth domain. In the Netherlands, hardly any attention is paid to arithmetic, although many vocational students still tend to find it hard and need it. Also little time is spent on handling data. A shift in emphasis in these types of education towards these two content areas of mathematical literacy seems preferable to better prepare students for MBO.

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