# THE CHALLENGES OF TEACHING STATISTICS IN SECONDARY VOCATIONAL EDUCATION

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*The challenges of teaching statistics in vocational education, an underresearched area, are likely to be different than in general education due to the focus on a particular occupation. The current paper addresses the question what these challenges are. Through interviews with teachers, apprentices and supervisors as well as analysis of the curriculum and classroom instruction, we identified such challenges. These include the difficulty to engage students and prepare them for diverse workplaces with different levels of mediation by technology. Moreover, competence-based projects, common in vocational education, require artful integration of theoretical and practical knowledge, and the design of representations that assist future employees to draw appropriate conclusions.*

## CONNECTING SCHOOL AND WORK

One of the key challenges in statistics and mathematics education is to engage students by giving them a sense of purpose and utility of the concepts and techniques they learn (Ainley et al., 2006). One way, both in general education (Dierdorp et al., 2011) and vocational education, is to seek inspiration for designing engaging statistics education in professional practices and thus make a connection between disciplinary content and future work. After all, as Lave (1988, p. xiii) noted: “It seems impossible to analyze education – in schooling, craft apprenticeship, or any other form – without considering its relations with the world for which it ostensibly prepares people.” In vocational education, this relation between education and occupation is apparent and the vocational area is indeed an interesting but underresearched area of study: It is where teachers and students face the challenge of connecting abstract disciplinary knowledge to its usefulness in occupations. We therefore expect that research in general education can learn from research in the vocational and workplace domain.

However, we should also note that the differences between school and work statistics are big (cf. Noss et al., 1999) because school and work practices entail very different aims, tools, communities, rules and divisions of labour. For example, school statistics is mostly general but workplace statistics is typically context-specific and mediated by technology – which is the reason that Hoyles et al. (2010) highlight the need for Techno-mathematical Literacies (which include statistical literacy). The term Techno-mathematical Literacies (TmL) refers to the technology-mediated nature of mathematics at work and the need for communicating quantitative information.

To gain more insight into these challenges we draw on a three-year research project on TmL in Dutch senior secondary vocational education (MBO), which prepares for intermediate-level occupations. This project came to focus on laboratory work. Common in industry, but also in health services and safety institutes, laboratories are statistically rich and subject to rapid changes in work organisation, hence interesting places to study the challenges that vocational teachers face when preparing their students.

In this paper ask: *What are the challenges of teaching statistics in vocational laboratory education?* Articulating these can provide a basis for improving the teaching and learning of statistics in vocational and presumably other settings. The challenge of preparing students for the technology-mediated use of statistics, for example, is a general one – just like the challenge of engaging academically less able students. We do not confine our analysis to challenges that teachers experience themselves but also include those that we inferred from discrepancies between school and workplace approaches to using statistics.

## DUTCH SENIOR SECONDARY VOCATIONAL EDUCATION (MBO)

To sketch the setting of our research we first provide information on the MBO school system. About 40% of Dutch senior secondary students (aged 16-17) attend general education or pre-university tracks; the remaining 60% enrol in senior secondary vocational education (MBO). Levels 3 and 4 of MBO are just above basic school qualifications but much below Bachelor level. MBO used to have attainment targets for each MBO occupation (including hair dresser, baker, electrician, lab technician). For mathematics and statistics in many technical programmes this was a list of about fifty topics. Attainment targets that were less relevant for the occupation were ignored by mathematics teachers and general subjects were generally considered separate from the occupation. Over the past ten years vocational education has become more and more competence-based (Van den Berg & De Bruijn, 2009). There are now qualification files for 237 occupations which are formulated in terms of what starting employees should be able to do. The effect has been that subject knowledge such as mathematics is taught and assessed less than about ten years ago. In the file for lab technicians, for example, references to the statistical knowledge required are scarce and broadly phrased (e.g., “basic knowledge of mathematics”; “care for quality”).

## THEORETICAL BACKGROUND

Hardly any statistics education research has been carried out in vocational education. Therefore hardly anything is known about the challenges of teaching this subject. Given the fact that vocational education forms a link between general education and workplaces, it is likely that we can yet draw on workplace research in this area. We can also learn from international trends of competence-based education.

The workplace research most relevant to our research is that by Hoyles et al. (2010). Key trends in workplaces such as automation and computerisation of work processes are likely to lead to particular challenges. Hoyles et al. (2010) analysed these trends and the effects on what employees need to know about mathematics and, notably, statistics. Bakker et al. (2009) described a way to draw on employees' rich context knowledge but often poor knowledge of statistics by designing alternative representations of statistics that do not draw on inaccessible symbolic language. Key artefacts (boundary objects) in work processes were reconfigured in software (technology-enhanced boundary objects) so as to allow manipulation and easy interpretation. Teaching required hybrid expertise of statistics and work processes, hence our collaboration with workplace trainers.

The main reasons for introducing competence-based education in our country were first to prepare students better for specific vocations and second to take into the changing population of students (Van den Berg & De Bruijn, 2009) – those who find general knowledge hard to learn and consider themselves doers rather than thinkers, of with language or personal problems. Like in many vocational systems in the world, projects and simulations are often used to stay close to particular work tasks. The underlying reason for such pedagogic measures is the general acknowledgement of the situatedness of cognition and problematic transfer of general knowledge to everyday situations (e.g., Lave, 1988).

## METHODS

To identify the challenges we analysed interviews with fourteen teachers (18:05 hours in total) at four different vocational laboratory schools (MBO) – three schools were relatively close to the university and one teacher in the fourth school was interested in the theme of our project and provided us with access to its teachers, students and supervisors. As a background to understanding the challenges mentioned by teachers we also studied their course materials and observed several lessons to get a sense of how course materials were used. We further conducted interviews with eight supervisors of apprentices in a variety of labs (in total 10:40 hrs), one school and two workplace managers (2:20 hrs), nine apprentices in the workplace (4:20 hrs), 27 apprentices at release days at school (5:40 hrs). With the help of three teachers we analysed 35 final apprenticeship reports to see what statistical technique apprentices used and how well they did so. In addition, we undertook four workplace tours in different labs (2:10 hrs), spent a day of observation and interviewing in one lab, and collected several prototypical artefacts that represented how statistical knowledge was mediated (e.g., Standard Operating Procedures including calculations, graphs, data etc.). This background information helped us derive challenges that teachers did not explicitly mention.

The interviews were transcribed verbatim and coded for challenges experienced by teachers. These were categorised into seven different but related challenges summarised in the next section. We used the remaining data sources to offer explanations and further background to these challenges.

## CHALLENGES

### 1. To cope with limited resources

All teachers complained that their hours for disciplines such as statistics had diminished due to longer apprenticeships (work placement) and the introduction of competence-based education – trends that several teachers considered to be a matter of economising on costs. In practice this meant more time on projects and learning on demand, and less on general subjects such as languages and mathematics. There is generally very little time for teaching statistics, for example one hour per week for the first two years. Yet the topics encountered in labs are numerous (Bakker et al., 2010). Moreover, both teachers and students noted that students had often forgotten many topics by the time they became apprenticed. A related challenge therefore is to keep their knowledge fresh and available over the course of the years even if not required in a particular company.

### 2. To engage students in learning statistics

All teachers and supervisors considered it important for students to understand the how and why of statistical techniques, but they also characterised their students as "doers, not thinkers". They found it challenging to engage them in disciplinary knowledge that is not immediately linked to what students see as their purpose: becoming a lab technician. We have interviewed students who were able to attend general education but had deliberately chosen the vocational route because they thought this was better preparation for becoming a lab technician or because they preferred doing something practical. However, most vocational students have failed in general education for whatever reason. We return to this point in the last section.

### 3. To make statistics visible to managers and colleagues

Teachers had a hard time to convince their managers and some of their colleagues that students needed some disciplinary knowledge such as statistics in order to develop the competences formulated in the qualification files. In most cases, the number of teaching hours for subjects such as mathematics, statistics and the languages decreased considerably. The time available for teaching is often dedicated to projects that simulate some work task typically found in the workplace. Managers and even colleagues of the mathematics or science who taught statistics often thought that disciplinary content could be taught "just in time", just before it was needed in a project. We probably do not have to convince the reader that teaching hypothesis testing (t- and F-test are common in lab work) has to be carefully prepared, especially to vocational students, who typically have not succeeded academically in general education. These observations illustrate that teachers found it hard to make statistics visible to their managers and colleagues. From the literature we can derive an explanation.

It is well known from the research on workplace mathematics (of which a large part actually is statistical in nature) that employees tend to say they do not do any mathematics, even if mathematics educators observe them using it (Noss et al., 1999). We have also experienced this: One supervising lab technician claimed his work only involved "pluses and minuses", but when he showed us around we saw technicians modelling chemical reaction processes, using extrapolation, slope and other mathematical concepts. When confronted with this observation, he responded this was chemistry rather than mathematics. We refer to this phenomenon as the Janus head (two-faced) nature of workplace mathematics and statistics: Where employees see working with numbers as part of their discipline (in this case chemistry), we as mathematics educators see mathematics being part of their work. It is only if we look for the use of statistics in workplaces and deliberately try to improve production processes that it becomes more visible (Bakker et al., 2006). This trend is corroborated by the omnipresence of black boxes in which most of the mathematical models and statistical techniques used at work are crystallised (Williams & Wake, 2007).

The drive to make the work error-free, one manager commented, has led to a situation where the younger generation often no longer knows what happens behind the screens. The paradoxical situation is that this hardly ever leads to problems – those have been ruled out by the system – but we did hear concerns about this situation; many lab technicians found it important for apprentices to understand the why and how of what they were doing and we have evidence from observations in one lab that blindly following procedures can lead to waste of materials and time. The tension observed can be seen as a result of the black box phenomenon that Latour (1999, p. 304) described:

> … scientific and technical work is made invisible by its own success. When a machine runs efficiently, when a matter of fact is settled, one need focus only on its inputs and outputs and not on its internal complexity. Thus, paradoxically, the more science and technology succeed, the more opaque and obscure they become.

The Janus head black-boxed nature of statistical knowledge required might explain why the qualification files pay so little attention to it and why teachers found it so hard to convince their managers of its importance.

**4. To prepare students for the technology-mediated nature of work**

Teachers often ask the question what they should teach their students and how. What do students need to understand about more complex statistics if it is carried out by a computer system? The fact that t-tests are used in many labs does not necessarily mean that an MBO lab technician should understand the formula or be able to perform one by hand, or even with a software package.

One of the teachers' key challenges that we think are relevant to education more generally is thus how to prepare students for the technology-mediated nature of statistics usage at work. One question here is whether students should learn the background of, say, statistical process control, before they use pre-fabricated SPC charts or whether they should learn SPC in relation to spreadsheets straightaway. The common assumption among teachers seemed to be that theoretical introduction with the conventional representations is the basis for practical usage. Previous research in a car factory has shown that this assumption is problematic (Bakker et al., 2009) and our observations in laboratory education corroborate this. For most students the step from symbolic representation, whether SD, t-test or correlation, to what can be inferred from them in practical terms is simply too big to teach in limited instruction time available for each topic.

Labs vary in terms of automation and computational tools, which means that schools have to prepare students for both manual and automated computation. Computations are not always taken away from employees. In some labs (about 14%, see Bakker et al., 2010), all calculations were automated in Excel sheets or dedicated computer software (such as LIMS: Laboratory Information Management System). In most others, a mix of computational tools (calculator, Excel, software) was used. The general image from the interviews was that calculations had become easier over the years because of software and automated machines, but what lab technicians need to know has not become less, only different; for example fluency in Excel has become more important. With computations outsourced to software, it becomes important to know something about the software and what it is doing. In one lesson we indeed observed how a teacher clarified to students the difference between computing something in Excel by column or by row – something relevant to statistics education we rarely find in a textbook.

**5. To prepare for a diversity of workplaces**

Teachers are well aware that their students may choose to work in very different labs. Should all students then learn what is required in the most advanced labs? Where chemical and clinical-chemical (medical) work involves correlation, regression and validation, the biological work often has a more qualitative nature (recognizing types of crystals etc.). Microbiological work does require good understanding of powers and logarithms, because amounts of bacteria are reported in powers of ten. Interestingly, common measures of centre easily turn out problematic when working with powers of ten. One supervisor preferred medians and geometrical means over arithmetic means but did not expect MBO level technicians to understand these alternatives.

**6. To keep up with innovations at work**

Laboratories change rapidly due to technological innovations. For example, students learn to calibrate machines in the old-fashioned way, but modern companies have big analysers that can be calibrated with a press on a button. The statistical background of calibration – measurements modelled by regression lines and correlation coefficients – has been completely blackboxed in such cases. Employees state they only judge the correlation coefficient to see if the measurements have been precise and accurate enough (e.g., 0.999964 was considered very good).

The aforementioned rapid developments at work raise the challenge for teachers to stay up to date. This is not easy once a teacher is 'caught' in a teaching job. Those who have a background as lab technicians themselves typically stay in touch with old colleagues and friends on these developments. However, those with a background in mathematics or science teaching find it harder to develop a good image of trends at work and their implications for curriculum change.

### 7. To develop their own statistical expertise

Most teachers we interviewed did not feel expert enough to assist students with the statistics required in their projects. Adding specialist teachers to the team was no option because there was a tendency to keep the number of teachers for each student as small as possible to make supervision easier for everybody. Workplace supervisors differed considerably in terms of statistical expertise and could not always help students either. Finally we were struck by the fact how vocation-specific statistics could be: The type of statistics taught by mathematics teachers was often considered too general to be useful for lab technicians, who thought in terms of method validation, reproducibility and stability, rather than correlation and variation coefficients.

## TO CONCLUDE: MEETING SOME OF THE CHALLENGES

In answer to our question what are the challenges of teaching statistics in vocational laboratory education, we identified seven challenges illustrated above. Some challenges are the consequence of competence-based education (1, 3, 7), one of the student population (2), and some of the changing nature of work (5, 6), in particular the technology-mediated nature of statistics in workplace (4). Many of the challenges are related. For example, the technology-mediated nature of using statistics at work not only raises the question of how to prepare students for it, but also contributes to the invisibility of this disciplinary knowledge at work and hence at competence-based education.

One challenge we see, but teachers did not address explicitly, is how they can help their students to develop the number sense required (Bakker et al., 2010). From the interviews with supervisors we assume this requires the integration of disciplinary knowledge typically developed at school and practical knowledge developed through experience at work. For example, whether a measurement value is judged correctly also depends on experience with the range in which that value typically falls. Judgement of correctness presumably draws on multiple resources including disciplinary and more workplace experiential knowledge. To conclude we mention how some of the challenges are or could be dealt with in practice or in research.

### Teacher apprenticeships to stay up to date

One important way in which teachers can stay up to date with recent developments at work is by means of teacher apprenticeships. Teachers, in particular those with a disciplinary background in mathematics or science, get the opportunity to work in a company for a few days to see how what they teach informs apprentices' work. One teacher of statistics we interviewed was very enthusiastic about this opportunity. In his case, he felt reassured that the topics he taught, such as statistical process control, were indeed used in ways that he propagated in his lessons. However, the general picture from the limited research on teacher apprenticeships (de Schutter, 2009) is that organising them and convincing teachers to take part is not easy. Moreover, not every workplace is suitable as a learning site for teachers.

### Diversity of labs

The way in which lab schools address the diversity challenge is to start with a general programme for statistics and tie the statistical aspects of lab work to the variants chosen. The biggest school we investigated had six different variants from which students could choose in their last two years. However, small schools did not have the resources to offer more than two variants (e.g., chemical and medical).

Diversity is not always problematic, because students are also diverse. They have different interests and qualities, and look for laboratories in which they can flourish. Likewise, companies select students that seem to fit in their type of labs. Some are good at routine work, other function better in non-routine work.

Workplaces also demonstrate a high degree of adaptivity which is possible due to the diversity of employees and tasks in a lab. If tasks turn out too difficult or important for apprentices or beginning lab technicians, they are carried out by higher-level or more experienced lab technicians. Thus workplace systems are serving as an ecology adapting to particular gaps or weaknesses in apprentices' knowledge. Such adaptivity and division of labour also has another side: We were told about lab technicians with an affinity for statistics who were given the opportunity to develop their statistical knowledge and become the team's statistics expert.

### Finding alternative representations

One of the main challenges in our view is how to deal with the discrepancy between how statistical measures and techniques are typically represented at school on the one hand, and how they are used in practice on the other. In course materials standard deviation and the t-test are typically represented in a symbolic language with ∑-signs – a language that is inaccessible to most vocational students. Our impression from observations and previous research (Bakker et al., 2009) is that many teachers and trainers think the essence of, say, a t-test is captured by its formula, just like the mean by its calculation, and that they see little opportunity to represent such concepts alternatively, or to emphasize their meaning in usage. However, what intermediate-level employees need to know about such techniques is what their purpose and utility

(Ainley et al., 2006) are and how they should be interpreted when produced by a computer system, and some conditions of usage. To us it seems sufficient for student lab technicians who do not plan to attend higher professional education to know that a t-test is useful for comparing means of data sets (e.g., to check if a new instrument is as accurate as the standard), and what it means that there is a significant difference. The little time attributed to teaching the t-test (typically one lesson) is perhaps better spent on such insights, including how to perform a t-test in Excel, than on explaining and applying the formula.

The problem of representation of such statistical concepts and tests was dealt with by Bakker et al. (2009) in the context of process improvement in a car factory. To avoid the symbolic language about process capability indices, they designed relatively simple, visual computer tools with which employees could get a sense of what these indices conveyed, and how their indices could be manipulated by changing mean, control limits or specification limits. These tools proved to facilitate communication between employees with diverse educational background. We therefore expect that it is in principle possible to convey the practical usage and implications of many statistical concepts and techniques in the context of work without anxiety-evoking formulae. We see ample reason to continue this line of research, especially in vocational settings where we can observe the connections between school and work practices and test out ways to engage students in seeing statistics as useful for a clear purpose: work.

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**REFERENCES**

Ainley, J., Pratt, D., & Hansen, A. (2006). Connecting engagement and focus in pedagogic task design. *British Educational Research Journal, 32*, 21-36.

Bakker, A., Hoyles, C., Kent, P., & Noss, R. (2006). Improving work processes by making the invisible visible. *Journal of Education and Work, 19,* 343-361.

Bakker, A., Kent, P., Noss, R., & Hoyles, C. (2009). Alternative representations of statistical measures in computer tools to promote communication between employees in automotive manufacturing. *Technology Innovations in Statistics Education, 3*(2). Online: www.escholarship.org/uc/item/53b9122r

Bakker, A., Wijers, M., Akkerman, S. F. (2010). The influence of technology on what vocational students need to learn about statistics: The case of lab technicians. In C. Reading (Ed.), Proceedings of the Eighth International Conference on Teaching Statistics (ICOTS8), Ljubljana, Slovenia. Voorburg, NL: ISI.

de Schutter, J. (2009). *Succesvol docentenstages realiseren: Ervaringen, praktijkvoorbeelden en aanbevelingen voor het mbo.* [Successfully realizing teacher apprenticeships: Experiences, examples and recommendations for Dutch MBO]. Hoorn: van Beekveld & Terpstra.

Dierdorp, A., Bakker, A., Eijkelhof, H. M. C., & van Maanen, J. A. (in press). Authentic practices as contexts for learning to draw inferences beyond correlated data. To appear in *Mathematical Thinking and Learning, 13*(1&2).

Hoyles, C., Bakker, A., Kent, P., & Noss, R. (2007). Attributing meanings to representations of data: The case of statistical process control. *Mathematical Thinking and Learning, 9*, 331-360.

Hoyles, C., Noss, R., Kent, P., & Bakker, A. (2010). *Improving mathematics at work: The need for techno-mathematical literacies*. London: Routledge/Taylor & Francis.

Latour, B. (1999). *Pandora's hope: Essays on the reality of science studies*. Cambridge, MA: Harvard University Press.

Noss, R., Pozzi, S., & Hoyles, C. (1999). Touching epistomologies: Meanings of average and variation in nursing practice. *Educational Studies in Mathematics, 40*, 25-51.

Van den Berg, N., & De Bruijn, E. (2009). *Het glas vult zich. Kennis over vormgeving en effecten van competentiegericht beroepsonderwijs; een review.* [The glass is filling up. Knowledge about the design and effects of competence-based vocational education. A review]. Amsterdam/Den Bosch: ECBO.

Williams, J. S., & Wake, G. D. (2007). Black boxes in workplace mathematics. *Educational Studies in Mathematics, 64*, 317–343.