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## TOOLS, ARTEFACTS, RESOURCES AND PEDAGOGY—STORIES OF INTERNATIONAL STATISTICS EDUCATORS

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**ABSTRACT** Our recent research investigated the experiences of educators teaching statistics as service courses at universities. We conducted interviews by email with participants from many countries and whose teaching reflects diverse settings, student groups and disciplines—a microcosm of higher education today. We now focus on the tools, artefacts and resources respondents identified as critical to developing their teaching. These include computer and internet technology; data sets, texts and research and human resources, such as master teachers or teaching pools. Teacher development can be characterised as “the enhancement of the knowledge and capabilities to function as a teacher” (Gordon & Fittler, 2004) and is bound up with student learning. Hence tools and artefacts harnessed by educators to develop their teaching are resources for enhancing student learning. Our approach draws on activity theory, based on the work of Vygotsky, Leont’ev and colleagues, and emphasising mastering tools in collective and individual development. Vygotsky extended the idea of physical tools as mediators of change to psychological tools or mental tools. Case studies from our investigation are used to explore how the educators constitute their teaching identities in relation to cultural tools.

### INTRODUCTION AND THEORETICAL FRAMEWORK

We recently conducted research investigating the ideas of statistics educators around the world about teaching and learning statistics in university ‘service’ courses. These are courses aimed at students who are majoring in another discipline (such as engineering or psychology). We now take an activity theory approach to explore how the participating educators use tools, artefacts and resources to develop their practices and how, in a dynamic way, cultural tools contribute to shaping and transforming the pedagogies and teaching identities of these educators.

Recent literature on research in education indicates the breadth and scope of activity theory as a lens for investigating educational phenomena. Activity theory is not a unified theory, and has many different facets and derivatives such as socio-cultural theory, cultural-historical activity theory, cultural-historical psychology and others (Holtzman, 2006). Indeed, Chaiklin (2001) introduces cultural-historical psychology as the solution to the riddle: “What is over 75 years old, but still a baby?” Originating in the theories of Vygotsky, Leont’ev, Luria and their colleagues and students from the Soviet Union, activity theory and its derivatives are being developed by contemporary western researchers in diverse contexts, fields of research and disciplines. For example, Engeström (2001) develops principles of cultural-historical activity theory to present a study of expansive learning in a hospital setting. Edwards and D’Arcy (2004) explore the relational agency of two student teachers from a socio-cultural perspective. Lawrence and Valsiner (2003) present a socio-cultural account of internalisation and externalisation processes in the context of a shoplifting event. Brown and Cole (2002) invoke principles of cultural-historical activity theory to guide the design of activity systems for enhancing the educational experience of children in after-school hours. The contemporary articulations of activity theory, though varied in focus, have philosophical commonalities including a non-dualist approach to understanding the formation of the human mind and society and a focus on the “interaction between an individual, systems of artifacts and other individuals in historically developing institutional settings” (Holtzman 2006, p. 6).

The idea that physical tools are mediators of change was extended by Vygotsky to psychological tools or mental tools. To Vygotsky (1981b, p. 140): “*The most essential feature distinguishing the psychological tool from the technical tool is that it directs the mind and behaviour*

*whereas the technical tool, which is also inserted as an intermediate link between human activity and the external object, is directed toward producing one or another set of changes in the object itself”.*

This means that psychological tools are aimed at mastery or regulation of oneself or others, rather than controlling the physical environment. In a dialectic way, these human transformations lead to the need for further mental tools that again give rise to new ways of conceptualising and acting in the world. Mental tools, for example, scientific theories, are cultural. They are created and passed on to others through social processes and socially structured practices. In Vygotsky’s thesis, cognitive functioning is shaped by the sociocultural setting (Vygotsky, 1978). Mediation by means of symbolic tools, especially language, serves as the mechanism for this shaping.

Vygotsky’s idea that psychological tools transform “*the entire flow and structure of mental functions*” (Vygotsky, 1981b, p. 137) is most pertinent to our society with its rapid technological transformations. For example, the ways we use our memories and other mental abilities have changed dramatically with “extra-cerebral” tools (Leont’ev, 1981, p. 64) like the Internet, data-bases, computer software, search engines and calculators. These have taken over the function of storing vast amounts of information and of processing information by means of complex algorithms, thus allowing for increased expertise and more complex mental actions by humans. Technological tools, cultural artefacts and communication systems—language, writing and symbols—transform the ways societies and individuals function. Moreover, each shared artefact, for example a text-book or a video is itself the seed of continuity—a means of passing on knowledge and culture from one year to the next, even from generation to generation.

In this paper, we explore the tools, artefacts and resources employed by statistics educators to develop their teaching practices. Teacher development can be characterised as “the enhancement of the knowledge and capabilities to function as a teacher” (Gordon & Fittler, 2004). Empirical research on teachers’ development, with student teachers as well as practising teachers, has suggested that representations of development expand from a focus on self and the role of the teacher as instructor to a focus on the task and teaching situation to a focus on student learning (Burn, Hagger, Mutton & Everton 2003; Åkerlind, 2003). Renshaw (2003, p. 358) extends the representation of a teacher’s function as going beyond merely ensuring that students learn; teaching requires critical reflection on what students learn, in what context and with what goals “and to reflect on *who* has the opportunity to learn *what*” (italics in original). That is, teacher development encompasses an increased capacity to take responsibility for meaningful learning, and to understand and take into account the significant political, ethical and social dimensions of student learning.

## **METHODOLOGY**

### **Context of the Study**

The setting for our exploration is a collaborative research project investigating the experiences of statistics educators teaching service courses at university (Gordon, Reid & Petocz, submitted). Statistics educators practise in many disciplines and contexts and are diverse in professional orientations, pedagogic backgrounds and training. Statistics is taught as a major subject in its own right but also as a ‘service’ course in a wide range of fields and disciplines including science and engineering, biomedical courses, business and economics, psychology, nursing and education. Hence statistics students as a collective are a microcosm of the diversity in ability, motivation, academic and cultural background that Mann (2001) suggests is a hallmark of higher education today. Teaching statistics as a service course presents a further level of complexity and challenge to educators, as students who are required to enrol in a quantitative methods or statistics courses do not necessarily have an interest in the subject and may not wish to engage with any study perceived as mathematical (Gordon, 2004). Indeed, it is well documented in the literature that courses in statistics or quantitative methods are seen as particularly difficult for some student groups and can generate anxiety and apprehension (Onwuegbuzie & Wilson, 2003). Statistics service courses, therefore, offer singular and interesting arenas in which to investigate cultural tools in pedagogy and professional development.

### **Method**

Our research questions can be formulated as:

- What tools, artefacts and resources did the educators harness to enable their teaching?

- How did the educators constitute and develop their pedagogies in relation to these tools, artefacts and resources?

The investigation consisted of a three-phase series of e-mail interviews with statistics educators from around the world. Participation was invited through an electronic request to the membership list of the IASE (International Association for Statistics Education) and Australian bulletin boards. Thirty-six IASE participants took part in the first email interview, with 32 completing the full series of three interviews, an indication of the engagement of respondents with the project. The remaining four carried out partial interviews before our cut-off date for data collection. The IASE statistics educators were from many countries including Argentina, Australia, Belgium, Brazil, Israel, Italy, Netherlands, New Zealand, Slovenia, Spain, Uganda and the USA. Most interviews were conducted in English (one was bilingual with English questions and Spanish responses). An additional nine interviews (seven completed, two partial) were conducted with Australian educators who responded to requests through departmental bulletin boards. The resulting interview transcripts of over 70 000 words formed the raw material of our study.

The participants taught statistics at universities in a range of contexts. They taught at various levels, from pre-degree and first year to postgraduate, using various teaching methods including traditional, large-group lecturing, tutorials and small research groups, problem-based learning and distance education; in some universities, statistics teachers pooled their strategies and resources to work as a team. Many participants reported teaching service statistics to student groups in several disciplines, with courses ranging from the traditional areas of physical, health and social sciences, business, economics and management, engineering, psychology and education, through to less common areas such as theology and liberal arts.

The interview protocol consisted of an initial series of six questions, reflecting our original research focus on educators' ideas about teaching and learning statistics in service courses. These questions were followed by up to two rounds of further questions which explored participants' responses in depth. The six initial interview questions were as follows:

Q0) First, some background information please: What country do you work in? What type of institution do you teach in? What level of students do you teach statistics? What discipline areas do you teach statistics in?

Q1) Tell us some more about the context in which you teach statistics.

Q2) What do you consider to be the most important aspects of statistics for your teaching?

Q3) What do you think makes a good statistics student?

Q4) What are the attributes of a good statistics teacher at university?

Q5) What approach or approaches would help you develop as a statistics teacher at university?

Questions 1 to 5 were posed in a deliberately open way to enable the participants to explore their own ideas rather than we, the researchers, eliciting responses in a specified direction. After studying the initial reply, we sent a second interview with questions following up and probing each participant's responses. These follow-up questions explored the thread of thought that was prompted by the original question and so depended on the individual response. Finally, a third interview was sent with further questions to elicit clarification and in-depth explanations of the responses given. The third interview also included an open question (Is there anything else that you would like to tell us about any aspect of statistics teaching and learning, or your development as a statistics educator?) as well as a request to evaluate the e-mail interview method.

Hence, the interview process was a written version of the usual face-to-face interview, with the modification that at each point in the process the respondent had a record of all previous communication including their own responses, and both interviewers and respondents could continue the dialogue in their own time. A critique of this method of e-interviewing is being undertaken by the researchers with data from the participants (Reid, Petocz & Gordon, in preparation). In addition, we have previously written about specific aspects of teachers' experiences from the data: teachers' views of the importance of communication skills for their service students (Gordon, Reid & Petocz, 2005) and teachers' ideas about recognising and developing good statistics teachers at tertiary level (Petocz, Reid & Gordon, 2006).

The iterative e-mail interview provided the participants with an opportunity to reflect on and expand their initial responses to questions. We found that the responses were well considered, and, at times, participants clarified and refined previous statements. Pseudonyms were chosen by the

participants themselves and included unusual choices such as ‘Henry VIII’ and ‘QMmale’. Excerpts from interviews in this paper are reported under these pseudonyms.

In this paper we focus on participants’ responses to initial and follow-up interview questions that pertain to the tools and artefacts shaping their pedagogies. In the next section we first summarise the range of cultural tools harnessed by the participants. The body of our findings comprises of four case studies that illuminate in more depth the role of tools and artefacts in the pedagogy and development of the educators. Finally, we discuss the significance of the findings.

## **FINDINGS: RANGE OF TOOLS**

A content analysis of participants’ responses revealed that the educators drew on a wide array of tools, artefacts and human resources to enable their teaching and develop their pedagogies. Tools included spreadsheet and statistics packages for processing statistical data, such as Excel; technology for illustrating concepts and facilitating interactive learning, for example, Internet applets and graphics packages; and communication tools, varying from overhead projectors in the lecture theatre to videos and communication media, as well as web-based systems enabling virtual networking, problem based learning and distance learning. Common artefacts reported were data sets, case studies, text-books, media reports and journal publications, while human resources included teaching teams, conference presentations, professional networks, voice coaches and formal and informal discussion groups. Many of the respondents mentioned symbolic systems such as mathematics, or subsets of mathematics (algebra, arithmetic, calculus, graphs), as well as cognitive systems such as mind-maps. Interesting omissions from this list were formal professional development courses and calculators (perhaps as taken for granted in the statistics classroom today as pens and paper). The latter omission is particularly salient from the activity theory perspective as it suggests that a historically valued human skill in the practice of statistics—the ability to perform calculations speedily and accurately—is now in the background.

There are many ways to organise these data; we found it useful, analytically, to consider the tools reported by participants in different activities: firstly in actions and interactions aimed at developing their teaching—in the background of their teaching—and, secondly, tools, artefacts and resources used when actually teaching—in the classroom. Thirdly we discuss tools in students’ activities, and, finally, symbolic or mental tools to be mastered by students. We elaborate on these categories below and provide short excerpts as clarification. Further amplification is provided in the four case studies that follow.

**(1) Professional tools for teachers.** These tools and resources were used by teachers in activities in the background of their teaching, to enhance and support skills, or to prepare for the task of teaching, or in their own professional development as teachers. In most of these ‘behind-the-scenes’ activities the educators evidently drew on human resources through direct interaction within their institutions and national/international cooperation. Respondents also referred to some artefacts in the form of materials or published matter. These activities and resources are listed below.

Interaction with others: Observation of master teachers; Attending other teachers’ lectures; Conversations about teaching; Support from serviced departments; Multi-disciplinary teams; Pedagogic training; Voice coaching; Teaching surveys.

National/international cooperation; Networks (eg CAUSE, Consortium for the Advancement of Undergraduate Statistics Education); Professional meetings (eg IASE, International Association for Statistical Education); Professional teaching materials (eg from IASE); Conferences (eg ICOTS, International Conference on Teaching Statistics); Journals in statistics education (eg JSE, Journal of Statistics Education).

Anette said that if she had more time: *“I think I would spend more time on reading IASE materials, trying to find something interesting from the Internet, keeping better contact with the colleagues I happen to know, taking part of more conferences on statistical education and trying to make new contacts there.”* Natalie, on the other hand, wrote that: *“By working together as a team that shares teaching materials we end up with consistent quality, and more time for creating new materials and improving current ones. As well, the course doesn’t fall over with the regular staff turnover and in fact, the turnover can be a positive thing as we’re continually revitalised with fresh ideas, enthusiasm and creativity.”*

The brief excerpts above show the interrelated nature of human resources, artefacts and technology in the developmental activities (planned or actual) and the teaching preparation cited by our respondents.

**(2) Tools for the teacher “on the job”.** Our respondents identified diverse tools and resources for specific teaching tasks and deployed during the time respondents were teaching, that is, working with students. In this category respondents mostly mentioned artefacts (such as data sets), with relatively few human resources (such as tutors). Technological devices (computers and communication systems) played a large part and facilitated different aspects of teaching. In all, our participants mentioned the following artefacts, tools and resources.

Data (real, current, from students, from computer archives); Problems (real, research, directed); Assignments; Case studies; Projects; Laboratory sessions; Examinations; Classroom activities; Examples of analyses; Computer simulations; Curriculum approaches (eg PBL, problem -based learning); Media reports and job advertisements; TV/radio programs.

Learning guides; Lectures; Powerpoint slides; Overhead projectors; Videos; CD-ROMs; Historical lessons or anecdotes; Worksheets; Notes (maybe with gaps for students to fill in); “Worry questions”; Templates for solutions to problems; Statistical tables; Textbooks; Discipline-based journals (eg in nursing or economics) with examples of uses of statistics.

Communications media (eg Skype, SynchronEyes); Learning systems (eg ALEKS, Assessment and LEarning in Knowledge Spaces); Spreadsheet and statistics packages (Excel, SPSS, Minitab, R/S+); Internet and applets; Graphics packages (eg ESCI, Exploratory Software for Confidence Intervals). Computers in lecture theatre with projection facilities.

Teaching teams; Tutors; Teaching assistants; Guest lecturers.

An example of the use of real data is given by Ron Fisher who described his primary classroom activity as: *“the analysis of real data and real data problems. ... To me, the essence of statistics is that of answering a real-world question. ... Not only do I try to incorporate newer statistical thought into my classes, I am constantly updating my examples, and looking for new applications that will interest my students. Not only do I do this for the students’ sake, it also makes the class much more interesting for me, since I am interested in the world around me.”* Hence, Ron Fisher links classroom teaching and preparation to the wider, societal context of statistical analysis as well as to his own self-development.

Leigh focussed on the interface of her own actions in the classroom with those of students: *“Very often I start the class by collecting data from the students then and there. I can set them a practice question to do while I enter it into Minitab. ... We have lots of real datasets available in Minitab and on our network.”* Leigh’s comment illustrates the integration and ongoing transformation of actions, artefacts and technology. Data developed during a classroom activity become an artefact through storing the data set on a computer and this information is then ready for a different and future classroom activity, namely statistical analysis, using a software package, Minitab.

**(3) Tools for students directed by the teacher.** The two excerpts above illustrate that some of the tools used by educators in the classroom are for their own instructional actions, others are integral to pedagogical process, but are essentially students’ tools directed by the teacher. We now focus on artefacts and tools implemented in students’ activities. Participants specified a wide range of learning tasks and actions carried out by students individually or collectively. These included:

Data gathering; Working on group assignments; Oral presentations; Explaining to a neighbour; Class discussion; Electronic discussion; Peer support; Small-group problem solving; Collaborative learning; Virtual groups; Virtual experiences; Social interactions; Working as research assistant; Carrying out research.

In her email interview, Cara reviewed her use of newspaper clippings in class to stimulate students’ abilities to think critically about statistics. *“At the beginning of each lecture I present students with interesting examples of misuse of statistics in daily newspapers and advertisements; I also encourage them to find examples of misuse on their own and present them in class. ...Students seem to have a lot of fun discussing these issues. At the beginning they are probably not aware of their development as critical thinkers; later on they might recognise the fact that they are becoming more sensitive with regard to cases of stats (mis)use.”*

Henry VIII explained the benefits of students taking a ‘hands-on’ approach: *“I think they learn more because they see real data being analysed, something they can relate to their professional careers, and also because they can quickly see the results, being spared long tedious manual*

calculation or graph drawing. (Also, here is the added attraction of working with a computer, which is still a novelty for most students, who usually only use the machines they have for games and web chat)."

**(4) Mental tools for students.** Symbolic tools, especially language and sign systems play a prominent part in Vygotsky's thesis on mental development, being a guide to thinking and "mastering oneself" (Vygotsky, 1978, p. 55). In this study mathematics and language were specified as mental tools by many respondents, as well as other cognitive tools including visualisation, images in memory, mind map and models.

Interestingly, mathematics was seen as a controversial learning tool by our participants. Some thought it essential for students to master mathematical skills, others that mathematics blocked and hindered students' statistical learning. Henry VIII reported that little mathematics was needed for the courses he taught: "We usually avoid doing mathematical demos of theorems and properties." Leigh went further, terming it "a mistake to call the subject mathematics, at least the way we teach at this level." She explained why: "Because so many students walk into a maths class and say 'I'm hopeless at maths'! In this class we are addressing questions about the real world through collecting and looking at data."

In contrast, Daria suggested that mathematics was fundamental to the education of scientists. "Every 'scientist' should have a minimum knowledge of calculus. The mathematical background helps in developing the ability to solve problems and in the process of generalization."

In a different vein, focusing on students' communication skills, Maria reported that: "I include in the course activities that imply written or oral communication of statistical analysis results. For example, in the computer laboratory sessions they carry out practical tasks using statistical software to solve problems. They must prepare a written report at the end of this session answering several questions. ... To improve oral communication skills I would like to include in the course an oral presentation. The number of students and the time limitation has prevented me from including them in the statistics course until now. However, the in-class discussion and the activities developed by students in groups provide them some training in oral communication."

Henry VIII reported that to prepare medical students to consult and collaborate with a statistician they needed to understand the language and principles underpinning statistical work: "I think the first step is establishing a common language. I'd first try to make the students understand the concepts, models and assumptions which are the basis of the statistician's work."

Our theoretical approach indicates that tools, artefacts and human resources are dynamic, transforming and interrelated in activity. That is, rather than viewing artefacts and tools as separate and static objects, or human interactions as distinct from tool use, we propose systemic and dynamic relationships among tools, artefacts and human resources. We have explicated some of these relationships in the summaries and brief excerpts above.

## **FINDINGS: CASE STUDIES**

We now review the experiences of four educators whose teaching is situated in diverse contexts. Andrew and Horace reported teaching in the traditional lecture mode while QMmale and Heintje described their practices in problem-based learning environments. These case studies illustrate more deeply how tools, artefacts and resources both shape and are shaped by the educators' pedagogic actions and goals.

**Case study 1: Andrew.** Our first case study exemplifies the diversity of tools, artefacts and human resources used in one of the three contexts we have outlined: 'on the job' teaching. Andrew is a New Zealand statistics educator who teaches a wide range and level of statistics students, including very large (1000+) first-year classes in biostatistics.

Andrew describes his teaching as "fairly traditional". Early in his interview he identifies the "most important" aspects of statistics for his teaching, referring to data sets from current research and human resources in the form of guest lecturers. These are teaching resources used in his 'classroom' to motivate students. Andrew comments, too, on constraints of the institutional setting that impact on his teaching.

"An ability to call on current data sets which have been generated from local research or from recently published papers. Even at first year level students are surprised at the wide level of application of statistics. ... I have recently called on examples from marine science, human nutrition and

*epidemiology. A guest lecture or two from scientists and others who are generating data for analysis helps make statistics interesting. This is in keeping with the collegial nature of a university if it is possible to cross the barriers that now exist between the various departments in a university. These barriers have big impacts on funding and at times it can be difficult for a subject like statistics.”*

In terms of the calculation aspects, Andrew makes the point that the historically useful books of statistical tables are viewed by some as redundant today. However, Andrew’s remarks below suggest that he still views statistical tables as having their place as learning tools, although he acknowledges that software packages are more essential tools for students.

*“Some other people believe that the use of tables should now be avoided in statistics and instead a program like Excel should be used. I am not convinced at this stage that this is a good idea... . In the biostatistics paper which I teach to the large first year class I use SPSS but this is largely because most of the health professionals at this university have SPSS available on their desks and it is the package used by them almost exclusively. Statistics majors should of course have access to other packages like R/S+ etc.”*

Andrew’s lectures to very large groups seem to depend on a traditional range of lecturing tools. He prefers typed notes and overhead projectors to PowerPoint presentations. His remarks below show the interrelatedness of his method of teaching (direct instruction), artefacts (pre-typed notes with gaps) and the tools for presenting the information (two projectors).

*“There is a need to give the students clear and concise notes and be well prepared. Never think that you can just pick up last year’s notes and present these. This usually displays a lack of interest in the subject, which is easily noted by the students. Also, if very detailed notes are handed out at the start of the semester for the whole semester you must be prepared to add to these notes otherwise the feeling of disinterest can be present again. It can be good to ask questions in the lectures even in the large classes. Personally, I do not use PowerPoint in lectures but instead use two overhead projectors with pre-typed notes containing gaps handed out to the students at the start of each lecture. Students then complete the gaps during the lecture. The two projectors allow the data to be clearly present and it can be referred to as you go through the analysis of the data.”*

In addition, Andrew makes extensive use of artefacts from the surrounding culture such as media reports and job advertisements. These enable his pedagogical actions and also motivate student activities and class discussions.

*“Almost every morning in the media there is some mention of an application of statistics, whether it be to an opinion poll or political survey (not particularly interesting) or to some health issue (more interesting). It is very good to draw attention to these reports. Recent ones which I have used relate to meningitis, screening for cervical and prostate cancer, increased incidence of diabetes and a possible relationship with breast feeding (highly controversial but interesting), folate levels in mothers of child bearing age and dolphin habitat selection and behaviour problems.*

*If these issues are drawn to the attention of the students and possibly discussed in lectures they can be enormously beneficial. The raw report on its own may not capture the interest of a student but if the report can be related to what you are covering in a course then that is enormously beneficial from the point of view of motivation. The teacher may be able to show these links. The reports also identify some areas where statisticians may be able to get jobs because students see a report from a particular group and sometimes they know of those people. Every week in the news I have found a major report involving a statistics study.”*

Andrew identifies his role as an instructor effectively guiding and steering student learning in his large classes by helping students see the connections between the statistical content and concepts he is teaching and applications in research, media reports, controversies and employment opportunities. Within his traditional approach Andrew draws on technology, such as software, other people, such as scientists, and cultural artefacts, for example data sets. All these arise from and are part of the wider society. Andrew views his statistical teaching as relevant to advancing current human conditions by enabling and encouraging students to evaluate medical and scientific research as well as providing students with employment opportunities.

**Case Study 2: Horace.** Our next case study concerns an Australian educator, Horace, who developed his own software as an instructive tool. By providing visual representations and interactive graphical simulations Horace aims to support students’ understanding of statistical concepts for their



study of psychology. In his first email interview Horace immediately referred to this software, describing how he used it in the classroom.

*“I give lectures that are in some ways traditional in that I introduce topics, give definitions, work through examples, and try to justify and motivate everything. But I also often use my ESCI software, which is intended to provide vivid graphical representations of concepts, multiple representations, interactivity, and in some cases simulations. For any key concept, e.g. standard error, I aim to give a take-home vivid image (the mean heap) that is linked to the definition, a formula, explanations, and examples. I hope the image will be the anchor for understanding.”*

In statistics classrooms, software is often used to process data—to do the number crunching—so enabling students to master the software could be an instructional aim in itself. However, Horace states explicitly that his aim in using the software was to support and transform students’ capabilities to understand statistical concepts.

*“In the lecture I swap screens every now and again from regular overhead to the computer screen showing ESCI, and I show a simulation, or an example, and talk about the vivid images. These are designed to link into the exercises that students will do, using ESCI, in their labs. The aim is to talk about the stats concepts and the images and the examples, and as little as possible about the software and how to drive that.”*

Looking beyond the classroom, Horace expressed his hope that enhancing students’ understanding of statistical concepts would develop their capabilities in the future, enabling them to evaluate research reports, as this would be important in their work as psychologists.

*“I hope students come to think more conceptually, to use the images and labels I introduce, and to feel more confident about stats and their stats knowledge. I hope also that they take a more ‘judgement’ approach, rather than a ‘maths, correct or incorrect’ approach to choosing a statistical analysis and interpretation, and reading and evaluating a research report.”*

Horace described student understanding in operational terms—as actions. *“If someone can explain in words, draw a picture, give the definition, state an example, and show they know when to use something, then that’s a pretty good operational definition of understanding?! (If they can write the formula, that’s a nice bonus!).”* He went on to expound the idea that the visual imagery provided by the software could develop memory. *“Anyway, I concentrate on pics early, and use them as much as I can as a basis for definitions, formulas, explanations, and examples. But there is a lot more than just pics. The pics may be especially helpful for memory, and there is lots of evidence that imagery in memory can be valuable. I hope all students benefit from this approach.”*

The above excerpt is a practical illustration of a key proposition in activity theory: mental capabilities are generated through activity. Thoughts and images are not formed in the brain; they are the function of the brain. (Leont’ev, 1981). That is, there is no landing pad in the brain awaiting the arrival of images, understandings or memories. It is by means of our mental and physical actions, that we master tasks, develop our mental capacities and transform collective knowledge into personal understanding.

The interview excerpts quoted so far have shown that Horace viewed his software as a tool for developing students’ understanding in the classroom and beyond. At the end of the interview, Horace explained that the interactive software was also a tool for his research, and so a means of connecting him with the wider community. Interestingly, Horace indicated the relationship between collective and individual development in his view—by helping people understand statistics better, he hoped to improve the practices of psychologists using statistics.

*“My main research area is statistical cognition. That’s the study of how people think about statistical concepts, the misconceptions they hold, and ways to help people overcome misconceptions. I’m interested in finding ways to persuade psychology to improve its statistical practices. I develop interactive software based on vivid graphical representations of basic statistical concepts. Having more time to work on that research, develop that software, and develop ways to extend its use in my stats teaching would be the most valuable way for me to improve my stats teaching.”*

Horace summed up an integrated approach to developing his teaching and research.

*“For me, a key aspect is the integration of teaching and research. The classroom is my lab. My software is a research as well as a teaching tool. I write articles about cognition as well as stats (and the teaching of stats). A related challenge is to think about what materials and approaches will be best*

*for the psychologist who is teaching stats, but who is not a stats teaching specialist and who simply wants materials and guidance to help get the job done efficiently and effectively.”*

The interview excerpts show that Horace’s teaching identity is inextricably interwoven with the development and use of his graphical software. Pedagogically, he views the software as a tool for enhancing student understanding of statistics and its applications both in the classroom and beyond the classroom in students’ future professional lives. The software is also a tool for Horace’s self-development linking his teaching and research in ongoing cycles of transformation. Further, in a broader, societal context, Horace reported his mission to advance the statistical practices of psychologists through research on cognition as well as to try and provide tools and materials that would guide and help fellow psychologists who are teaching statistics.

Our next two case studies exemplify the approaches and experiences of two Netherlands educators (from different institutions) whose teaching environments are in direct contrast to the more traditional, lecture-based settings outlined in the cases of Andrew and Horace.

**Case Study 3: QMmale.** QMmale described the problem-based learning approach adopted by his university as *“learning without instruction”*. He outlined how this approach worked in his practice and the particular challenges of adapting the problem-based system for the mathematics and statistics courses servicing economics and business.

*“My institution has adopted the pbl, problem-based learning, approach of teaching. In this approach, small tutorial groups (12-14 students) are at the heart of the system, coached (but not taught) by staff. Student self-study is essential in this system: compared to other systems, students have few contact hours (class hours): typically 8 per week. For most academic topics, independent self-study initiated by learning goals created by students in their tutorial sessions work fine. However, in math and stats, some students have difficulty to master topics without having more support. In a kind of ad hoc way, we created some support outside pbl tutorials. Given budget and large number of students, this support is not optimal, being mainly large group lectures (500 students).*

*In a PBL system, no ‘real’ teaching takes place (cannot be the case, since class hours are so limited that one would not have sufficient time to teach). ... However, math and stats are service courses in the program, and we have spent much time (and trials) to find out if service courses can work in the same context as the major topics for econ and buss students. We think we cannot avoid to have a kind of hybrid system, for two reasons: our students are in general poorly intrinsically motivated to do math & stats (since it is ‘only’ a required subject they should take) and 2, their prior knowledge (education) is extremely heterogeneous.”*

This PBL system depends primarily on artefacts including problem sets, textbooks and electronic tools to guide and steer learning. Lectures are used as a resource for identifying and ameliorating misconceptions.

*“So our system is strongly based on pbl principles (and therefore: mostly learning without teaching, since most of the learning takes place outside class, with our problems, textbooks and electronic tools as learning devices). But it provides more steering than other courses in faculty, which are in the traditional pbl format. So we will have lectures in which common misunderstandings are highlighted, have directed problems as capstones for the student learning, instead of undirected problems that allow students to define their own learning goals, and so on. So some explicit staff steering, without traditional teaching.”*

According to QMmale, the function of the teacher in this PBL approach changes. Rather than delivering direct instruction, the teacher’s task is to design ‘problem’ tasks that challenge and engage students as well as to coach or assist students with learning projects.

*“Our students are not that different from students in the rest of the world: they need education to learn math & stats. However, education does not necessarily imply teaching. ... The stimulus staff can provide in that learning is in the design of problem tasks (I have called them assignments, since the word problem tasks is not that well known) that are so intriguing to students that students have (get) intrinsic motivation to solve those tasks, and (as the necessary step to do so), to learn the new subjects required for the tasks. (Problem tasks are constructed in the spirit of Vygotskian ideas of designing a sequence of tasks that are always in the zone of proximal development when having finished earlier tasks.) So in a pbl based institution as ours, teaching is replaced by two other activities: the coaching of tutorial groups of students, and the construction of this type of problem tasks.*

*... I regard modern electronic learning devices as one of the most important tools for stats education. ALEKS is one such tool I experiment with. Most important: the device should be adaptive, should take the prior knowledge, prior education as a starting point and build on that. Most traditional learning environments will not adapt to students' knowledge."*

QMmale described the teacher's role in the PBL system as knowing and designing learning tools, though this is supplemented with direct instruction, tutoring.

*"Once again: our pbl system is really different from most systems, but in our situation, good lecturing is hardly of any value. Teachers do not teach, so no need for being an excellent lecturer. What remains is the tutor role (coaching the students), and the designer role: constructing problem tasks and other materials. The last role requires deep content knowledge, the first much less."*

To QMmale, tools enable teachers to build on students' experiences and knowledge.

*"I found the pbl-system adopted in our university a very attractive approach. It is certainly not unique: there are a lot of related approaches, all strongly learning directed instead of teaching directed that achieve similar aims. Once such an approach is adopted, the role of the teacher is changed into that of 'facilitator': more in search for tools that might help specific students in their learning process, than being a tool yourself. I regard that last change as stimulating."*

Thus QMmale expresses the essence of his pedagogy as finding or designing tools to enable student learning—rather than being himself the tool for students' learning. This role as facilitator was the basis for his perceived self efficacy.

**Case study 4: Heintje.** Our final case study focuses on students' actions building a "distance community of inquiry". Heintje's disciplinary area is Psychology. She described the context of her teaching as follows. *"I am supporting students in computer supported collaborative (distance) courses statistics and methodology, which are joint in special research projects."*

Heintje reported that the difference between computer-supported collaborative learning (CSCL) and face-to-face teaching of psychology statistics was the *"explicitness of the communication and the challenge to verbally communicate and formulate everything."* She elaborated on the challenges of developing a virtual community of inquiry via this communication tool, explaining how the communication system shaped students' interactions in the learning project, challenging their social, cognitive and communication skills in the process of contributing to a collective body of knowledge.

*"That means that every participant is challenged to formulate his or her messages exactly, to reflect critically on his or her own assumptions and reasoning, before sending a message to the group. ... So CSCL is a challenge in critical thinking (and reflecting) and a social challenge. Verbal communication is more explicit and there's no support (and, interpreted as an advantage, no distraction) of visual cues. It takes longer (a training in patience and self regulation) to establish relations and group cohesion."*

To Heintje, the study of statistics was connected with the development of students' awareness of scientific thinking. In addition, students needed to develop and practise specific skills. Students' learning actions were supported by a real research program.

*"An important instrument of the empirical evidence of psychological constructs is statistics. Linking statistics to everyday practices of psychologists makes students aware of the importance of empirical evidence and its instruments, statistics and methodology. Without these evidence based theories and fundamentals a psychologist would not be recognised as a scientist, able to diagnose, assess or treat his or her client. Without this profound academic knowledge, one could also diagnose or assess with astrology or using one's intuition and make use of alternative treatments. This general awareness, is an important epistemological fundament for the program. The next goal is developing methodological and statistical skills by practising. All skills need practising. This practising is embedded in a real, research program, following all research steps and providing a way to experience the connections between the program elements."*

Heintje expanded, explicitly, on the role of the communication media in the collaborative construction of knowledge by the student group. She outlined the advantages, challenges and constraints intrinsic to the use of the electronic communication system in stimulating different dimensions of learning and development. These dimensions included not only technical competencies, such as computer skills and statistical procedures, but also the collective generation of reflective and critical thinking. Heintje's insight was that this collaboratively generated combination of technical and

social skills, attitudes and critical capabilities underpinned the students' training as professional psychologists.

*"First of all and especially for distance learning, bridging the time and space gap. Technology and communication media (especially computers) facilitate discourse and group learning for our students, who are widely spread all over the country. As already mentioned, working on a group task, exchanging messages and formulating ideas stimulates reflection and critical thinking. Thanks to communication media our (distance learning) students now are able to work on group assignments and tasks, a social construction of knowledge. Computer skills are developed, participants are challenged to create virtual group work and as a consequence develop their social skills (which seem to be important for most psychology students). They learn to support each other and regulate their learning approaches more actively, inspired by group ideas and hypotheses. The Internet itself provides a tremendous amount of information, easily accessible, and students will learn to discriminate between information and knowledge, sources of knowledge and how to evaluate knowledge. Critically evaluated knowledge (analysed and discussed by group members) is selected as part of their own body of knowledge. Instead of individual learning our participants will experience a zone of proximal development in which they'll generate more ideas and are stimulated to (self)reflection. All these (virtual) experiences will stimulate the development of competencies (the combination of knowledge, skills and attitudes) that are important for their future jobs. Computer visualisations facilitate the understanding of different procedures or features. Computer software (like SPSS or Excel) facilitates (statistical) computations."*

An exceptional and intriguing feature of Heintje's construction of herself as designer of the CSCL environment was her attention to the social and emotional dimensions of this learning environment. We asked Heintje to expand on the idea of *"more sociable CSCL environments"* and how such environments helped students to express their feelings.

*"A disadvantage of the present intranet structure is the lack of colour - symbols or instruments to express feelings or emotions, to compensate the lack of nonverbal cues. Missing a real live tone of voice, complicates the social aspect of communication and causes emotional, misunderstandings more easily. From this perspective, a computer supported environment is a rather cold, context. ... So, a combination of different media options that are easily accessible will probably satisfy the needs of our students, but a lot of technical research and development has to be implemented before all those wishes can be fulfilled."*

The excerpt above alerts us to a significant aspect of learning sometimes neglected—the emotional needs of students—the affective 'colour' of their interactions. Vygotsky (1962, p. 8) emphasised the affective dimension of mental development or capacity, affirming (poetically) that the separation of intellect and affect: *"makes the thought process appear as an autonomous flow of 'thoughts thinking themselves', segregated from the fullness of life, from the personal needs and interests, the inclinations and impulses, of the thinker."*

## **DISCUSSION**

In the summaries and case studies we have outlined a wide range of cultural tools, human resources and artefacts reported by our respondents. We term these tools-in-action to emphasise the inseparability of tools and their purposeful development and application in the practices of the participating educators. The case studies illustrate further how four educators constituted their teaching and roles in relation to their primary tools. Andrew portrayed his role as an instructor whose main aim was to illuminate statistical concepts and connect them with applications in science and medicine. The software Horace developed is a powerful tool for facilitating students' conceptual understanding through visual graphics and simulations, and is integral to his pedagogy and research as well as a means of helping advance statistical practice in psychology. Both Andrew and Horace used lectures to convey basic content. QMmale also evidently saw a role for lectures but these were a secondary means of communication in his problem-based learning approach. Sets of problem tasks are artefacts that enabled QMmale to transform his identity from *"instructional tool"* to facilitator of students' understanding. Heintje's aim was to create an environment in which students collectively generate knowledge for their professional lives. Heintje seemed to identify her role as designer and developer of a communication system that stimulates students' critical thinking as they collectively generate statistical knowledge. While Andrew drew on guest lecturers to enhance his classroom activities directly, Horace appeared to be acting solo in his classroom: his research and software were behind-the-scenes developments that

shaped his teaching. Both QMmale and Heintje, on the other hand, conveyed implicitly that they were part of an institutional group collaboratively developing the means for enhancing student learning. A key aim of the teaching approach of all four was to enable students to create connections between statistics, the serviced discipline and the wider society.

From an activity theory perspective, the conceptualisation of self and identity is inherently dynamic: human subjectivity is “immersed in the flow of transitions between individuals and the world” (Stetsenko & Arievidtch, 2004, p. 485). That is, according to Leont’ev’s account, individual agency and self-existence are continually transforming within dynamic and social transactions in the world. We have explored the role of tools as both being shaped and shaping the pedagogical identities and development of the statistics educators.

This leads to the question of how objects are connected with the mind. Bakhurst, an interpreter of activity theory, solves the problem by referring to the meaning of objects acquired by them in social practice (Bakhurst, 1988, in Cobb et al., 1996). That is, the “ideal” (in the sense of imagery, of being in the mind) existence of an object is completely different from its physical nature — the stuff of which it is made. It is an artefact endowed with social significance. To illustrate this, Bakhurst describes a pen as a form that objectifies a social purpose. The meanings that a community give to an object transform it into a cultural artefact which has ideal properties. These properties become accessible to our minds when we participate in the social practices for which the object was developed. Hence, writing with a pen gives it its “reality”.

This activity theory concept is exemplified in our findings. We have shown that artefacts, such as ‘real’ data sets, are imbued with different meanings according to the activities in which they are used: these confer the social ‘realities’ to the artefacts. A data set may be generated in statistical research and so serve a scientific purpose for the researchers, providing evidence supporting or opposing their hypotheses. The same data set could have a different meaning for students, being an instrument of learning, a tool for developing students’ analytic skills. Educators in this study have also described data sets in terms of pedagogical goals and actions, using the data set as a means of motivating students and of connecting students to the wider community of practising statisticians.

## CONCLUSION

Our study has practical and theoretical implications. On the practical level, the sheer number and variety in our data could stimulate us to reflect on the tools we use in our own teaching practices, and to examine the implicit assumptions underlying the content, presentation and evaluation of tools and artefacts in our classrooms and developmental activities. While some of the activities, tools and resources are specific to statistics education (for instance, collecting data from students, or analysing data with statistics packages), the majority are applicable to many disciplines (for instance, attending professional conferences, evaluating media reports, incorporating oral presentations). Moreover, any teacher will recognise and be familiar with some of these tools and actions, but is likely to find others that they have not considered. It might be a useful component of professional development to reflect on some of the less common resources and activities, such as job advertisements, language templates for solutions to problems, attending colleagues’ lectures, and having students work as research assistants, or even carry out research themselves. Some of the less familiar tools-in-action were explored in the cases studies: in particular, those of QMmale and Heintje explored the operation and meaning of a problem-based curriculum, an approach that is not general in statistics education (or other areas).

We could consider, too, incorporating new and different tools or approaches into our classroom activities and preparation. A recent report by Scott (2006) examines Australian graduates’ written comments on the *Course Experience Questionnaire*, a survey given to all graduates. One of the conclusions of this study was that specific disciplines tended to have a small list of commonly used learning methods, which were sometimes quite different from methods used successfully in other disciplines. Scott (2006, p.ix) writes: “*This suggests that there may be considerable room for exploring ways of using the preferred methods identified in one Field of Education in another field, where their application would be feasible but currently they are little used.*” Our analysis of the strategies and resources used by our participants uncovers a much broader range than would be commonly used by a single educator, and hence allows for such exploration.

On the theoretical level, activity theory leads us to consider how teaching is both organised within historically developed, social and cultural settings, and contributes to shaping and developing

human arenas, such as the practices of psychologists and other professionals. An interesting inference from the data is the emergence of an international community of practice: teaching statistics as a service course. The excerpts in the findings sections of this paper are quotes from educators in different countries, including Brazil, Italy, Slovenia, Spain and the USA, working in a range of discipline areas, yet these participants expressed common goals and described pedagogical actions that overarch the diverse cultures and contexts from which they arose. A further theoretical idea we explored is the interrelationship of mental and physical tools and artefacts in social practice. Both subjective aspects (ideas) and objective (physical) parts of human life are constituted, not in the head, nor in the external world of concrete objects, but in the performance of social activities (Bakhurst, 1988). In this way they are intertwined and give meaning to each other. For example, in this study participants reported how teachers, students and computers interfaced in an array of actions including communicating, storing information, solving problems, illustrating concepts and simulating experiments.

The interview data could alert us to think about the impact of teaching beyond the classroom, as Renshaw (2003) suggests. Technological advances mean that people encounter a rapidly growing mass of information during their lives. Statistics itself is a tool for helping people assess information critically and use it effectively for their own benefit and to develop their communities. One of our participants, César, explicitly referred to making students aware of their ethical responsibilities to use statistical knowledge correctly, and stressed the importance of drawing on good resources to ensure this correctness. We conclude with his insight (our translation from his Spanish original).

“... I always indicate to my students that lies are bad in themselves, but when they are based on statistics they are doubly bad, because they carry the power of conviction of numbers and sophisticated methods (which are esoteric and mysterious for many people). The idea is to provoke in students the ethical commitment that the statistical task requires. That for this it is necessary to acquire a thorough grasp of statistical theory, to know its extent and limitations, to be able to apply them correctly in practice and, in they have any doubts on the matter, to go to those who will know how to solve the problem correctly: a good book, a professor, a colleague.”

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