Johan Anton van Buuren - From subject-oriented to competence-based statistics education. An intervention study in a school of psychology (in Dutch)

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Note: ***A longer description in English is appended to the back of the Abstract as part of the same file***

Abstract

This thesis describes how statistics education has been redesigned and implemented in the curriculum of the school of psychology of the Open Universiteit Nederland. In stead of autonomous and separate traditional statistics service courses and courses in research methods, both kinds of courses have been integrated into a coherent whole, including psychological theory, to realize a better fit with the educational target goal: the autonomous study of science by carrying out (psychological) research.

Chapter 1 describes the arguments for this thesis. The literature refers to three possible causes for the problems that university students have in learning, remembering and using statistics. The first explanation looks at causes which can be ascribed to the students themselves: a deficient preparation in mathematics, a negative attitude, anxiety, low motivation and low self-esteem. The second type of explanation goes back to the contents of the subject of statistics. This subject is abstract and complex, and is taught in a compressed way mainly in the initial phase of the study, at a time when students are not aware of the meaning of research. The third explanation is found in the position of statistics within the curriculum.

In this thesis a solution for these problems has been provided by redesigning statistics education into a competence-based learning environment. The underlying idea for redesigning is to create a long-term programme for students in which a series of whole-psychological-research-tasks is carried out in a cumulative way. The expectation is that students in such a learning environment naturally become familiar with selecting and applying appropriate statistics techniques in a variety of psychological research contexts. Additionally the research assignments intend to support a better understanding of the value and importance of statistics in psychological research, to improve motivation for carrying out

research and to establish more positive attitudes towards statistics. Based on these expectations, concrete research questions have been formulated. For the (reconstruction of the) design process the Intervention Mapping approach has been used. The purpose of Intervention Mapping is to provide program planners with a framework for effective decision making at each step in intervention planning, implementation, and evaluation.

Following the needs assessment chapter 2 describes the first three steps in Intervention Mapping which provide insight in what needs to be changed to solve the problems. The first step consists of a detailed description of the desired behaviours (performance objectives). The second step is to identify important and variable determinants that precede and influence the desired behaviours. Since the positioning of statistics in the psychology curriculum is considered to be the cause of the problem in statistics education, determinants are investigated in the (external) learning environment. The discipline's position determines to a large extent how teachers can shape their education. The determinants not only define students' learning outcomes, but also students' learning strategies which in turn depend on how meaningful, valuable, useful, and secure students think education is (motivation, attitude). As a consequence, changing statistics education's position in the psychology curriculum, as mentioned in chapter 1, most probably will lead to the desired changes in motivations and attitudes and to a structural solution of recognized problems in statistics education. Finally, in chapter 2 determinants are tuned with the performance objectives. The resulting change objectives are pictured in a matrix. By doing so the goal of the intervention has been made concrete.

Chapter 3 focuses on the educational guidelines which will shape the change objectives. Guidelines which may scaffold and support the learning processes which are needed for the abstract and complex statistics content and which are applicable in carrying out psychological research have been found in "Cognitive Load Theory" (Van Merriënboer & Sweller, 2005), 'Meaningful Learning' (Ausubel, 1960, 1968), the 'Cognitive Apprenticeship Model' (Collins, Brown, & Newman, 1989) and the 'Theory of the Research Environment' (Gelso, 2006).The most important guidelines are: the activation of prior knowledge, the use of advance organizers, the provision of opportunities to deliberately practise and to apply statistics in a long-term programme of learning and application, the prevention of cognitive overload, and the design of a variety of authentic psychological research tasks.

Chapter 4 explains, based on the findings from chapter 2 and 3, how the learning and instructional principles and guidelines have been applied in the redesign of the learning environment. The design adequately fits the ideas of the 4C/ID-model (Van Merriënboer

1997), an instructional model that emphasizes the acquisition of complex skills. The redesign of the curriculum concerns two statistics service courses statistics, a SPSS-course, and three research methods courses. The bachelor thesis has been considered as the final stage of the research competency. In six consecutive research practicals (just as much as the number of integrated courses) the students become familiar with the reallocated statistics contents, research methods and psychology. The design of the integrated research practicals has been tested in two pilots. The formative evaluation of the redesign confirms its usefulness for statistics education for future psychologists. The integration of statistics, research methods, and psychology is appreciated positively, seems to help students overcoming their statistics anxiety, the studyload appears feasible and the electronic learning environment appears to trigger active engagement, exchanges of messages and critical discussions about findings between students. It has been decided to implement the statistics education design into the psychology curriculum using the label ‘research competency’.

The pilots did not offer the opportunity to investigate whether students achieved better learning outcomes than in the conventional approach of statistics education. Chapter 5 describes a cross-sectional investigation that was conducted among students who have been taught statistics education in the subject-oriented or traditional way and students who have carried out the first research practical, in which students meet for the first time statistics techniques like correlation, regression and variance-analysis. It is supposed that students in the redesigned competence-based learning environment gain a more positive learning attitude towards statistics, become motivated to conduct psychological research, will use more appropriate learning strategies, will gain more insight in statistics and better established statistics skills than it is the case in the traditional, subject-oriented learning environment. The research results confirm the assumptions: the competence-based learning environment distinguishes itself in a favourable sense in comparison with the traditional learning environment with regard to all these factors, although the effect-sizes are not large. Notable are is the mechanisms of attitude and motivation. It seems that in the subject-oriented approach to statistics education the (negative) attitude towards statistics prevails and that the motivation is hardly triggered, while in the competence-based approach the (negative) attitude has been neutralized and that students use a motivated and deep approach to study statistics.

Chapter 6 deals with results of a longitudinal study that was carried out among a group of students from the competence-based statistics education and a group of students from the subject-oriented statistics education. The pre-measurement took place three years earlier among students in one of the pilots and students who had participated in the same period in

a research methods course, meaning that this group of students already participated in one or more statistics service courses. Three years later, both groups of students have been studied for the second time using the questionnaire which also has been used in the cross-sectional research. Once again it became clear that the competence-based approach is favourably different from the traditional learning environment. Apparently the learning environment even induced significant interactions over time and again effect sizes were significant, though not impressive.

Chapter 7 reflects on the findings and results from the previous chapters and their implications for statistics education not only for psychology students of the Open Universiteit Nederland but also for statistics education in a more general sense.
It may be inferred that by integrating statistics and research methods into authentic psychological and professional learning tasks statistics has obtained both a more (psychologically) hidden (integrated) and a more prominent (omnipresent) position within the curriculum.

The school of Psychology of the Open Universiteit Nederland has taken the first step in shaping the research competency. Integration of statistics, research methods, and psychology is a challenging step. Integration opens the perspective for shared goals, close cooperation and coordination between teachers of different disciplines and for a better understanding of each other's profession.

Extended Description of Dissertation in English

The intervention study

My research is about an intervention in the curriculum of psychology at the Open Universiteit Nederland. This university is an institution for distance education. Students enrol during the year by buying a course (mostly 120 hours study time) which can be completed in two years. They study at home and for some courses they attend some group meetings.

The existing situation was that statistics courses were presented separately from the methodology courses, which implicated that the course program consisted of:

- two statistics courses: descriptive (ending with regression / correlation analysis) and inferential statistics (ended with ANOVA and nonparametric tests);
- one SPSS course;
- three courses in research methods;
- one course in literature search.

Of course – as could be expected – students experienced attitudinal, motivational and learning problems with the statistics courses. To solve this problem structurally I have introduced a new comprehensive subject in the curriculum of psychology: the *research competence*.

In this new program all former statistics and research methods courses have been rearranged and reassembled into a series of cumulative and concentric research cycles in the psychological domain. The new program is offering students the opportunity to realize the competence level of a 'scientist practitioner' by deliberately and programmatically practicing psychological research, generating and testing psychological theories. This in contrast with the former services courses program in which students had to deal with isolated statistical or methodological concepts and techniques.

In my dissertation I have described the process of rearranging and reassembling the learning materials using the protocol of Intervention Mapping (IM)(Bartholomew, Parcel, Kok, & Gottlieb, 2006). The advantage of this protocol over other intervention methods is the systematic use of transformation matrices for developing a theory- and evidence-based intervention. The IM-protocol includes six steps. The chapters in my dissertation follow the sequence of these steps.

In IM-Step 1 I conducted a needs assessment. In Step 2 I established program objectives to realize changes in the learning and teaching environments that better suit statistics education. In Step 3 I translated theoretical methods into practical strategies and instructional guidelines. In Step 4 I integrated the strategies and guidelines into an instructional design called the "Research Competence", in which students learn statistics by actively participating in a sequence of research practicals. In Step 5 I described a first investigation (survey): a cross-sectional comparison of the two different groups of students: a group which had been enrolled in statistics service courses and a group which had been enrolled in the first research practical in which some basic statistical methods were handled (comparison of group means in a descriptive way, by a t-test and by ANOVA, and bivariate regression). In step 6 I discussed process and effect evaluation.

Content of the dissertation

Chapter 1 – step 1 IM: Needs assessment: *From problems in statistics education to the goal of intervention.*

In this chapter I have described several explanations for the problems students and teachers meet in statistics education. The first series of explanations focuses on the student level (lack of prior knowledge, negative attitudes, low motivation, surface learning, disappointing study outcomes). The second series directs the attention to the learning environment (teacher): content, (density; limited period in which all statistical content must be learned at once) domain-specific characteristics (hierarchical, mathematical nature) and didactics. The third series of explanations focuses on the positioning of the service courses in the psychology curriculum. It has been argued that changing the position of statistics in the curriculum will lead to more substantial and structural solutions for the problems in statistics education than the implementation of interventions within existing statistics service courses. The desired change may be realized by integrating statistics and research methods into a continuous sequence of well-guided research cycles during the bachelor phase, which may also

scaffold and support the process of statistical thinking. Such an approach offers the conditions to regroup and rearrange the statistical content in series of more frequent and integrated research practicals that are steadily distributed over the bachelor stage. The approach may reduce cognitive load and support the creation of a learning environment in which students can actively apply statistics in a meaningful way in a variety of authentic psychological research tasks.

Chapter 2 – step 2 IM: *From intervention goal to change objectives*.

In this chapter students' aimed for behaviour in conducting research, understanding and applying statistics has been specified in concrete performance objectives (learning goals)(Table 2.1 in the book). The rationale behind these performance objectives was the literature about statistical literacy, statistical reasoning and statistical thinking, reflecting declarative, procedural and conditional knowledge, contextualized in the psychological domain. After having articulated the performance objectives I have identified relevant and changeable determinants of those performance objectives.

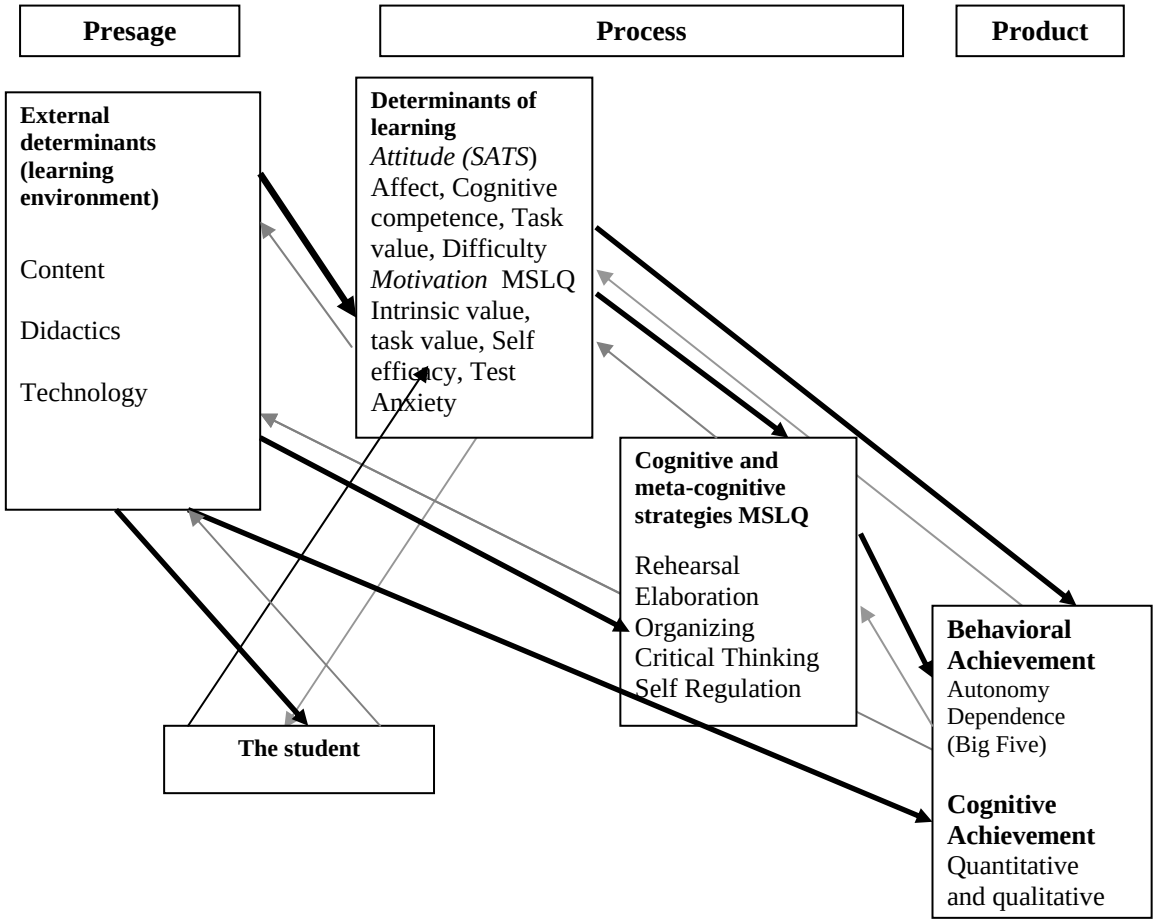

Figure 1 Model of self-regulated learning

Firstly I have searched for determinants at the curriculum level (rearranging content over more research practicals in which content is alternately learned and applied; didactics, technology). The assumption is that changing these determinants will positively affect attitudes towards statistics (less negative), motivation, the use of cognitive strategies (surface versus deep learning strategies) and learning outcomes. See Pintrich & Zusho's model of motivation and selfregulated learning (2003) and Pintrich et al. 's MSLQ (Motivated Learning Strategies Questionnaire, 1998) which we have completed with attitudes towards statistics (SATS, Schau et al., 1995). Attitudes, motivation and use

of cognitive strategies are considered as mediator variables between learning environment and learning outcomes, (see Figure 1).
The matrix of change objectives has been created by crossing each performance objective with each determinant. Change objectives have been linked to the population, the performance objective, and the determinant in concrete operationalizations (see Matrix I.1 in the Appendix on cd-rom).

Chapter 3 – Step 3 IM: *From change objectives to theory-based and practical educational instructions*
After I had identified the change objectives, I moved to Step 3 of IM to develop a theory- and evidence-based strategy map. A theoretical method is a general technique or process for influencing changes in the determinants of behaviors and environmental conditions. A practical strategy is a specific technique for the application of theoretical methods in such a way that it will fit the target population and the context in which the intervention will be conducted. Methods and practices have been found in Cognitive load theory (Van Merriënboer & Sweller, 2005), Meaningful Learning (Ausubel, 1960), Cognitive Apprenticeship Instruction Model (Collins, Brown, & Newman, 1989), and the Theory of the Research Training (Gelso, 2006). At the end of IM Step 3, I had constructed a list of instructional guidelines and practical strategies I wanted to include in the program, all based on theoretical methods and potentially covering all change objectives that I had identified in Step 2 (see Appendix I.2 on the cd-rom).

Chapter 4 – Step 4 IM: *From educational instructions to an integrated competence based instructional design.*
The Four-Component Instructional Design model (4C/ID, Van Merriënboer, 1997) has been chosen to integrate the various educational instructions in one coordinated blueprint of the Research Competence. See Appendix I.3 on cd-rom for the complete blueprint. Below (Figure 2) you see an abbreviated one.

Nr	**Research practical**	**Problem stage**	**Methods stage**	**Results stage**
1	**Parametric data-analysis** (120 h)	4 cases Psychology	- data gathering methods are given in cases - path model 2 variables - secondary analysis (on existing data)	*Comparison*: Means/standard deviation t-test/ANOVA *Association*: linear regression/correlation
2	**Survey** (120 h)	4 cases Psychology	- path model ≥ 2 variables questionnaire construction (survey) and administration (n ≥ 20 respondents) Likertscale - Cronbach's α	linear regression/correlation + moderation / mediation / interaction
3	**Literature search** (120 h)	Problem Theoretical justification Hypotheses	Latest research articles about a psychological phenomenon	
4	**Non-parametric data-analysis** (120 h)	4 cases Psychology	- (path)model 2 variables - secondary analysis (on existing data)	*Comparison* : Most used non-param. test-measures in Psychology *Association*: Most used non-param. measures for association, logistic regression loglinear analysis
5	**Experimental design** (120 h)	4 cases Psychology Causal relationships	Experimental designs Confounding influences	t-test / ANOVA + repeated measures + MANOVA
6	**Observation and interviewing** (120 h)	4 cases Psychology	Observation, Content analysis Depth interview Focus groups	Parametric statistics Non-parametric statistics + Cohen's kappa
7	**Bachelor thesis** (480 h)	Theoretically justified problem	All treated methods and techniques	All treated measures + Structural equation modeling

Figure 2 Blueprint of the Research Competence (summarized)

Figure 2 shows that in order to make empirical investigations in practicals manageable I had to break down the research process according to the research stages and the rules of the American Psychological Association (APA) for journal articles (Introduction ('Problem stage'), Methods, Results, Discussion, last 'stage' is omitted in the table). The Methods column and the Results column in Figure 2 show the content of the two subjects that used to be taught separately: research methods and statistics respectively. Each practical contains at least three different research assignments. The first assignment in a practical is a worked-out example (an expert solution) which aims to reduce the 'mental' or cognitive load (Lovett & Greenhouse, 2000); the second assignment is a less worked-out assignment (fill-in) where students have to contribute more, and the final assignment is the task in which students have to carry out their own research in accordance with the learning goals. Following the sequence of the assignments within each practical the intensity of the coaching decreases and the contribution of the student himself increases (scaffolding and fading). Not all components of the research process are emphasized equally in all practicals. In the first practical, called Parametric Data-Analysis, the Results stage is emphasized, which means that although examples and cases of complete investigations are given, most attention is given to the data analysis. In the second practical attention has been shifted to the second stage of the research process (Methods), but now we expect students to correctly apply the acquired statistics knowledge and skills (in this case regression and correlation), and to demonstrate their competence in extending this 'prior' statistical knowledge and skills to several specific features (moderation, mediation). I want to stress that Bachelor students in the Research Competence get acquainted with statistical techniques and crucial aspects of statistical literacy, reasoning and thinking in far more opportunities than they used to have at the time that they received only their two service courses. However, it is still about the same content. Note that I have limited the statistics content to the mean, the standard deviation and extensions of these to the analysis of variance and regression/correlation during the first two practicals. As a consequence students can construct a better insight into the mean and its characteristics, without confusing the concept with other (e.g. non-parametric) statistics. Furthermore all the statistics material that has been learned in prior practicals comes back in all other research assignments during the bachelor period. And thus students discover the necessity, functionality and utility of statistics, just by experiencing en being engaged in real psychological research. Working with real data and conducting authentic psychological research tasks increases motivation.

Finally, students' statistical knowledge should be interiorized properly by repeatedly performing data analyses. Students' knowledge should become transferable and deep understanding should grow as a consequence of the use of a variety of (psychological) cases (Van Merriënboer, 1997; Lovett & Greenhouse, 2000).The seven research practicals integrate seven former and separate statistics and research methods service courses.

It has taken several years to gain an insight into the consequences of a curriculum redesign, to evaluate the definite psychological research program and to select the appropriate delivery, sequence and content of statistical topics in every practical. During this period of tryouts students' motivation, affects, uses of self-regulating learning strategies (deep learning or superficial learning and their components) and learning outcomes have been monitored. Based on the positive results in the quasi-experiments, Open Universiteit Nederland decided to change the curriculum of statistics and research methods definitely. At this moment, however, the whole curriculum has just been realized. In September 2004 the last opportunity for students to complete the classic statistics service courses was discontinued and research practical 1 (Parametric data-analysis) was introduced officially. Gradually the other service courses have been replaced by Research Competence practicals.

In a number of pilots I got acquainted with the handling of research cycles (in an electronic learning environment. Remind that our students don't live at a campus: the OUNL is an institution for distance learning and students are free in choosing time and place to study).

Chapter 5 – Step 5 IM: *From instructional design to implementation*

In this chapter I compared all students who enrolled in the year 2003-2004 in the statistics courses with students who enrolled in the first research practical. I had a response of about twenty percent. To

find out whether the non response was a matter of Missing Completely At Random (MCAR) or have something to do with the subject (i.c. statistics education) I conducted a non response inquiry. Appendix III.1 on cd-rom describes this inquiry. Findings show that in my inquiry the non response is due to MCAR.

Dutch translations of the SATS (Schau et al., 1995) and the MSLQ (Pintrich et al., 1991, 1993) were used to assess attitude, motivation and cognitive strategies, using 1 to 5 points Likert scales, whereby 1 indicates 'don't agree at all' and 5 'I totally agree'. For the statistics performance test, seven open questions and one closed question were developed (for examples see for instance Reading, 1996). The answers and arguments on the statistics questions were evaluated and classified in accordance with the Structure of Observed Learning Outcomes (SOLO) taxonomy (Biggs & Collis, 1982). For Autonomy and Dependency Likert type items of the Big Five Scale (Goldberg, 1990) have been used. The questionnaire is to be found on the cd-rom (Appendix II.2)

All scales (including the statistics performance test) were analysed by the *Rasch model* for one dimensionality, misfits, and person and item reliability, followed by Structural Equation Modelling of the Rasch scales. The Rasch model analyses have been described in Appendix III.2 on cd-rom. The cross validation of the conceptual model is to be found in Appendix III.3 on cd-rom.

Raschmodel scores in all scales range from level -4 till +4 logits with a mean of 0. A one-way between groups MANOVA has been performed to investigate differences in attitude, motivation, cognitive strategies and learning outcomes. There was a statistical significant difference between the two teaching contexts, F (15, 452) = 4.616, p = .000; Wilks' Lambda = .867 and partial eta squared = .13. All hypothesized effects were in the predicted direction in favour of the competence-based approach (see Table 5.8 in the book).

Table 1 MANOVA for differences in means (in logits) between Competence-based (COMP) (n = 128) and Subject-based (SUBJ) (n = 340) learning environment

	***M* COMP**	***SD* COMP**	***M* SUBJ**	***SD* SUBJ**	***F***	***df***	**Sig**	***Part eta*^{2}**
Attitude								
Affect	0.67	2.03	-0.13	2.12	13.264	1, 467	.000	.028
Cogn Competence	1.47	1.57	0.74	2.08	13.121	1, 467	.000	.027
Value statistics	0.65	1.48	0.42	1.76	1.687	1, 467	.195	.004
Difficulty	0.32	1.19	0.77	1.52	9.048	1, 467	.003	.019
Motivation								
Intrinsic value	2.57	3.22	1.21	3.27	16.200	1, 467	.000	.034
Task value research	1.96	1.76	1.29	1.70	14.037	1, 467	.000	.029
Self-efficacy	1.19	1.93	0.35	2.78	9.837	1, 467	.002	.021
Test anxiety	-2.82	2.99	-2.06	3.37	5.090	1, 467	.026	.011
Cogn strategy								
Rehearsal	-0.26	2.09	-0.72	1.96	4.988	1, 467	.026	.011
Elaboration	1.85	1.87	1.69	1.76	.712	1, 467	.399	.002
Critical thinking	1.20	1.57	0.73	1.40	9.889	1, 467	.002	.021
Self-regulation	1.10	0.90	0.74	0.88	15.311	1, 467	.000	.032
Learning outcomes								
Autonomy	1.41	1.40	0.73	1.49	19.948	1, 467	.000	.041
Dependency	-0.71	1.79	-0.71	1.66	0.000	1, 467	.987	.000
Statistical knowledge	-2.21	2.09	-2.98	1.95	13.931	1, 467	.000	.029

Chapter 6 describes a longitudinal study. The effects are largely the same as in chapter 5. The Rasch equivalent methods can be found in Appendix III.4 on cd-rom.

Chapter 7 – Step 6 IM: *From implementation to evaluation*

In this step I have discussed the strengths and weaknesses of the intervention. Though the conducted studies are just the very beginning of comparing both curricula – I only had the opportunity to compare just a small part of both curricula - – the effects of the competence-based approach are promising. It strengthens my idea that I am on the right track. The studies included in my dissertation support the claim that integrated, research-based instructional designs can optimize learning outcomes in statistics. The new teaching context removes statistics as a discipline from a narrow, mathematically focused and anxiety inducing perspective to a research embedded context, related to the psychology domain, which triggers student's interest and engagement, and as a consequence, facilitates learning. Results are promising!

The new teaching context changes the perception of statistics. In stead of being perceived as a discipline with a narrow, mathematical focus and an anxiety-inducing approach statistics, embedded in a real psychological research context, now is recognized as a discipline which is related to the psychological domain and is triggering students' attention, interest and commitment. This drastically different perception will facilitate the study process. As a whole: results are promising!