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THE CHALLENGE OF TEACHING AND LEARNING STATISTICS IN TERTIARY EDUCATION

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Abstract: Taking into account quantitative, informatics, and technological demands by which postmodern society is faced, it is not surprising that there exists an increased interest in the discipline called teaching statistics. Statistics instructors and teachers in higher education encounter lots of obstacles while trying to teach their students how to upgrade their current base of knowledge, as well as to develop skills and competencies in this field. On the other hand, students face a great deal of problems while learning statistics, doing their assignments as well as taking exams in statistics. The main aim of this article is to provide a review of findings related to statistics teachers' skills, competencies, and knowledge along with those linked to students' motivation, personality, and attitudes. The subsequent group of aims includes giving some directions on how to improve teaching techniques and teaching materials in order to achieve better learning outcomes with regard to statistics. The following four, relatively new teaching approaches, were presented too: problem-based learning, anchored instruction, cognitive apprenticeship, and situated learning.

Keywords: statistical education, higher education, real-life examples, subject matter knowledge, students' anxiety

IZAZOVI PODUČAVANJA I UČENJA STATISTIKE U OKVIRU VISOKOG OBRAZOVANJA

Sažetak: Uzimajući u obzir kvantitativne, informatičke i tehnološke zahtjeve sa kojima se suočava postmoderno društvo, nije iznenađujuće što postoji povećan interes za disciplinu koja se naziva podučavanje statistike. Instruktori i nastavnici statistike u visokom obrazovanju susreću se sa mnogim preprekama prilikom nastojanja da svoje studente nauče kako da nadograde njihovu trenutnu bazu znanja, kao i da razviju vještine i kompetencije na ovom polju. S druge strane, studenti se sučavaju sa velikim problemima prilikom učenja statistike, izrade zadaće i polaganja ispita iz statistike. Glavni cilj ovog članka je ponuditi pregled nalaza vezanih za vještine, znanja i kompetencije nastavnika statistike, kao i za motivaciju, ličnost i stavove studenata. Sljedeća grupa ciljeva odnosi se na pružanje nekoliko smjernica o tome kako unaprijediti tehnike podučavanja i korištene materijale, u cilju postizanja boljih ishoda učenja vezanih za statistiku. Predstavljena su i četiri relativno nova pristupa podučavanju: učenje bazirano na rješavanju problema, "sidrišno" davanje instrukcija, kognitivno šegrtovanje i situaciono učenje.

Ključne riječi: statističko obrazovanje, visoko obrazovanje, primjeri iz stvarnog života, znanje predmetne materije, anksioznost studenata

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Introduction

Teaching statistics is a difficult and demanding process, in which not only teachers' subject matter knowledge is the thing that matters. Besides, his/her experience and pedagogical skills are of a great importance as well. It was shown that traditional techniques of teaching statistics are not as effective as expected [19]. Teaching only theoretical background and providing fictional examples do not lead to positive educational outcomes. In addition, students perform poorly, achieving insufficient grades on midterm and/or final exams. In turn, they become extrinsically motivated, having and expressing negative attitudes toward statistics. Their domain-specific (i.e. statistics) academic self-esteem decreases along with their level of self-efficacy. Students can also experience anxiety caused by the demands and complexity of statistics as an academic course. This is mostly due to teacher's failure to convince students that statistics is important and relevant to their further studies as well as to the future career after completing their studies [8].

Hence, there is a *triad* that includes a *teacher*, *student(s)*, and *teaching materials*. Statistics teachers could be well-experienced or could have less experience in their profession. One group of students might have a high level of previous knowledge and skills whereas another group might lack previous knowledge and competence relevant to statistics. Previous knowledge in the first place implies competences in the field of high school mathematics. Finally, teaching materials (e.g. textbook, learning handouts, additional resources, etc.) could be hard or easy to understand by students. In other words, they can facilitate or complicate the process of learning. Lots of students think that they have to memorize the contents of teaching materials as much as possible. However, statistics teachers want students to become statistical thinkers, to understand and comprehend some fundamental statistical concepts and ideas, and to be able to evaluate quantitative information and data [10]. These interactions between teacher, students, and teaching materials through the teaching and learning process are going to be explained in greater detail. But first, some alternative pedagogical approaches (as opposed to the traditional one) that are available to (statistics) teachers will be described in a few words.

Some alternative and contemporary pedagogical approaches to learning process

Problem-based learning (PBL)

In this pedagogical approach, students are encouraged to work in small groups in order to solve some open-ended, context specific problems [17]. They work together as active and self-directed problem-solvers [3] while teachers serve as facilitators of this learning process. Some effects of implementing the problem-based learning approach are: increase of students' intrinsic motivation, improvement in their problem-solving skills, improvement of critical thinking, and more effective transfer of knowledge to different kinds of problems. Additionally, group collaboration makes students study regularly, while teachers/instructors who are cognitively and socially congruent and flexible stimulate them to develop mental models relevant to problems as well as to continue with learning [18]. However, there are some shortcomings of this approach. The main one encompasses poor previous/background knowledge of some students who do not understand some basic concepts of a particular subject (i.e. statistics) and, as a result of that, are not able to apply their skills and knowledge to real problems.

The application of this approach into the process of teaching and learning statistics can be illustrated by the following example. Teachers split their class into e.g. four groups of five students in each. In each group, there is a student who understands statistical concepts properly and has a great level of practical intelligence. S/he is able to close ''theory-practice gap'' and to help other students to came up with their own ideas and options through the way of solving a particular problem. All students within all groups should participate in collaborative activities. The problems that are given to students are, as much as possible, the real-life examples of statistics. Teacher monitors and supervises the work of each group and estimates their level of knowledge and relevant ideas while approaching to the solution(s).

Anchored instruction

If teacher decides to apply this approach to her/his teaching process, s/he starts with an 'anchor' material, which is usually a video [5]. This material can be in the form of simulation, animation, or graphics as well. It is used to introduce a new lesson. Its contents should be adjusted to students' previous knowledge and should be short as well as enough interesting and engaging. Later classroom activities (debates/discussions, asking questions, bringing up various ideas and remarks, trying to answer teachers' questions…) are based on the aforementioned 'anchor' (e.g. video or simulation). Of course, students can watch it again, if they want to understand the contents of the current lesson better and more deeply. By using anchored instruction along with interactive learning environments, *generative* and *constructive* learning are being promoted [7]. In addition, this approach overcomes the issue of students' *inert knowledge*. A research conducted in this field showed that preservice mathematics teachers have positive attitudes and optimistic views on anchored instruction [12].

For instance, statistics teachers can show a simulation of tosses of a coin (the coin flipping trial/experiment) along with the distribution of number of resulting heads and tails. This could be done at the beginning of the lesson called "Bernoulli trial". From this stimulation, students can learn about the pattern of grouping equally likely outcomes. After this initial step, the discussion should be opened. Some misunderstandings can be overcome by looking again at the simulation.

Cognitive apprenticeship

This teaching approach is comprised of the following six teaching techniques/phases: modeling, coaching, scaffolding, articulation, reflection, and exploration [6]. First, teacher, instructor, mentor or tutor demonstrates how to solve a particular problem. Next, a student is expected to repeat these steps and to solve a given problem. This phase is called "modeling''. Hints and feedback to students are given within coaching phase (technique). In scaffolding, teacher adjusts his amount of help to the level of students' knowledge and competence. Thus, s/he does not help student do and figure out things (problems) with which the student is familiar. If the student absolutely does not know how to solve a particular part of the problem, the teacher helps him. Articulation is the process of demonstrating and verbalizing knowledge in order to clarify possible misunderstanding, overcome limitations and think more effectively. Reflection is the comparison of one's own work and thinking process to those of another student or the teacher. Reflection helps students to improve their problem-solving skills and to perform better. Finally, exploration means letting students solve problems by themselves, without any external help (from their peers or course teacher/instructor).

How can statistics teachers implement and use this technique/approach? For example, they can explain to their students how to draw a scatter plot. First, teachers demonstrate this on a blackboard (by referring to a table where data are arranged into two columns, each representing a variable). Students are asked to do the same thing and teacher helps them to do it properly (estimating the space to be occupied by this graph, drawing x and y axis, putting points/dots within the frame of the plot in a correct place…). These are the modeling and coaching phases. Next, teacher uses scaffolding: expecting students to do other tasks that are more complex compared to the previous one. S/he helps them when they really need help. Hence, teachers do not provide a redundant hints, help or support. They only help students in those steps to the solution of a problem that seem very difficult from the perspective of students. Then, teachers ask their students to speak up about issues they encountered during the process of problem-solving. Students also have to explain their way of solving problem (articulation) and to compare them with those of other classmates. Finally, teachers present a new problem that should be solved individually. In other words, each student has to work without the help of others and to produce a scatter plot (for example, two pairs of variables displayed in a single graph and drawn in different inks) that is in accordance with teachers' expectations. Students should explain the direction and sign of the correlation and to compare two pairs of variables with regard to the two aspects of correlation.

Situated learning or legitimate peripheral participation (LPP)

The main idea that constitutes the core of this teaching technique is: learning could not be separated from context, culture, community, social interactions, or other activities. Therefore, learning is not possible without collaboration and social interaction. Additionally, learning is usually an unintentional process and takes place as "legitimate peripheral participation" [13, 12]. Novices

(beginners) in a subject are, firstly, at the periphery of a particular learning community. They listen to their instructors, trying to understand subject matter and as they are becoming better in that subject, they move to the center of the community (i.e. their class, research group etc.). Of course, the terms ‘’periphery’’ and ‘’center’’ should be understood as metaphors that stands for the amount of knowledge that a student has in a specific point of time. Therefore, s/he has to be aware that s/he is not alone during the learning process and that s/he has to be involved into her/his social network within which knowledge is embedded.

Teaching statistics by using the situated learning approach is obtained by reinforcing students to communicate with each other and to ask teacher for further explanations and clarifications. Teachers can ask their students to conduct a research within a class. But first, they will conduct an example of the research and students will listen to them, write down notes and ask if they do not understand something. Next, teacher should choose a small group of students who seem to have an appropriate level of understanding of the research procedure. Then, they will ask their classmates (colleagues) about their socio-demographic background and give them some measures of e.g. cognitive needs, motivation, self-esteem… When they collect the data, they could proceed, by entering them into a statistical program where some statistical analyses should be performed. While doing so, other students can take notes and ask if something is not clear about the procedure. The rest of the students can also assist the first group of students who conducted research. In this way, they will learn through the means of social interaction, which is similar to the cognitive apprenticeship. The next step is to choose some of the other students and tell them to conduct a similar, small research among their classmates. In fact, this process illustrates the mechanism of legitimate peripheral participation.

Statistical teachers’ qualities, competencies, skills and knowledge

First of all, teachers should be able to create a positive, supportive learning atmosphere. Next, they should have deep understanding of students’ cognitive and other needs. They have to be able to facilitate the process of learning statistics, by carefully considering pedagogical and domain-specific techniques to be applied. Teachers should be aware of the notion that students learn by constructing knowledge as well as by active involvement in learning activities, and statistics teachers should not underestimate the difficulty that their students have during the acquisition of basic statistical and probability concepts [10]. Amy Smith and Ignacio Martinez-Moyano conducted a series of interviews with statistics teachers and concluded that teaching performance should be regarded in light of the following five teaching techniques/activities [20]:

a) Using real-life examples.
b) Highlighting and encouraging the understanding and interpretation of statistical procedures rather than their final results only.
c) Requiring exercises related to collecting data.
d) Demonstrating how statistics can be used badly.
e) Using simulation to encourage students to get insights into various statistical concepts.

Richard Walstra and his colleagues underscored the importance of technology while learning mathematically based subjects. Thus, the teacher should enable activities that are closely linked to the available technology. They stated that students have to encounter technology in the classroom and the real-world (active) approach should be employed by their teachers [21]. To put it in other words, statistics teachers should have good informatics (IT) skills and the ability to put lesson materials into the frame of their practical usefulness.

Andrew Gelman (along with his colleagues from the same department) developed a course on teaching statistics at the university level. During this course, students are ecouraged to participate in wide-ranging discussions, induced by the following questions [11]:

1. What are bad and good styles of teaching?
2. How to test and grade the students?
3. How to stimulate students' involvement and class participation?

4. How to manage and solve difficult situations with students?
5. How to teach to individual students?
6. What are particular issues in the process of teaching statistics?

First, these PhD students were taken the role of teaching assistants (that is, some kind of cognitive apprenticeship was used by their supervisors), next, they were providing anecdotes (specific situations that occurred with their students) and trying to figure out the best way to manage this kind of the presented issues. In terms of the aforementioned questions, statistics' teachers should have the following skills and competencies: being aware of the difference between good and bad teaching strategies and use the first ones; the capacity for making reliable, valid, and objective tests (exams) in order to accurately grade their students; motivating students to participate in class activities; ability to manage conflict resolution process; choosing an appropriate approach to work with some students individually; and ability to recognize and spot specific issues that they can encounter while teaching statistics.

Carmen Batanero and Carmen Diaz stated that statistics teachers do not think that they are well-prepared for teaching this subject [4]. This is not a surprising thing, taking into account that they should possess common and specialized content knowledge, knowledge about common students' (mis)conceptions, and knowledge of the design of instruction [2]. Therefore, there are a lot of demands that are put before the statistics teachers. It is difficult to meet all of them and it is not always fair to attribute students' failure to teachers' activities and negative qualities.

Jamie Mills and Dheeraj Raju provided us with some advice on how to teach statistics online. According to them, this kind of statistics teachers should [16]: administer short weekly quizzes in order to motivate their students to keep learning teaching materials, recommend a paper (printed) coursebook (thus, not only the online material), organize weekly meetings for students, and use class time to review materials covered in the foregoing week.

Statistics teachers should also possess a high level of social/emotional intelligence as they can understand problems students are faced with. To put it in other words, teachers have to be prepared to empathize with their students, to understand their point of view, to model emotional stability and patience while dealing with complex statistical lessons and problems, and so forth. It is clear that statistics teachers should have high level of logical/mathematical intelligence as well. This type of intelligence is mandatory in their field of teaching. Statistics teachers should be able to roughly assess students' levels of cognitive load and endeavor to reduce the complexity of instruction and matter presentation in order to make students develop and widen their own cognitive schemes (i.e. to mentally organize and construct knowledge by themselves).

Some obstacles that statistics teachers may experience and encounter during the teaching process are: students who are not motivated enough, students with poor background mathematical knowledge, the lack of a textbook of a good quality (lots of good statistical textbooks are written in English and there is a problem if students' mother tongue is not English or if they do not possess sufficient knowledge of English), and the shortage of technology in their classroom (problems with funds, investors and superiors who reject to give financial support for this purpose). There is one more obstacle: the time limit of a lecture that could not be sufficient for paying attention to each student and giving them individual feedback.

Students' personality, motivation, and attitudes toward statistics

It is preferable that students possess high levels of the three following traits/dimensions: conscientiousness (including: planning, organization, self-motivation, commitment and persistence), emotional stability (useful while encountering difficult problems that have to be solved within a short period of time), and openness to new experience (explorative and creative skills along with proneness to critical thinking). Ideally, they should have very high levels of *intrinsic* rather than *extrinsic* motivation. Thus, they should like statistics, enjoy while solving statistical problems and show genuine interest in this subject. In other words, they have to have positive attitudes toward learning statistics and perceive

this process as something that is fulfilling, satisfying and inherently reinforcing (i.e. cognitively stimulating as itself).

Here are the chief characteristics of an active, motivated, and successful student of statistics:

a) S/he considers statistics a useful tool for performing both classroom and external activities.
b) S/he has at least an average level of practical and contextual intelligence.
c) S/he is dedicated to her/his statistics assignments.
d) S/he tends to explore additional teaching materials, resources, and tools (e.g. software) related to statistics.
e) S/he thinks of statistics during her/his daily activities and finds some patterns in them.
f) S/he is able to transfer her/his knowledge in plain words to other classmates, because s/he understands statistical concepts, ideas, procedures, and their application.
g) S/he has a very low level of anxiety related to statistical exams and answering teacher's questions.
h) S/he wants to solve the same problems and work on the same tasks in different, creative ways.
i) S/he often uses the appropriate learning strategies and achieves very good to excellent results.
j) S/he usually has at least an average level of logical/mathematical intelligence and skills.
k) S/he is able to work and study collaboratively (however, this quality is optional and not common to all brilliant students of statistics).

The usage of learning strategies by (statistics) students is the essential factor of their academic success. Learning strategies facilitate the learning process and can be divided into five subcategories [22]: rehearsal, organization, elaboration, motivation, and metacognition. Students should be able to monitor the use of their learning strategies (i.e. to develop metacognition strategies and to use them skillfully), to organize the subject matter in a meaningful way as well as to elaborate it (putting it into a context, thinking of it in a critical way…), to motivate themselves and to frequently estimate the amount of their own knowledge (by self-testing).

For example, if students learn a lesson on t-test for independent samples, s/he could ask herself/himself: How can I make a distinction between this kind of t-test and the other types of it? Why these samples are considered to be "independent"? Can I make up an example whereby I can perceive the practical value of this statistical test? How can I motivate myself to memorize the formula used for its calculation? Have I made the link between previous statistical topics and t-test for independent samples? Of course, teachers can help students with employing learning strategies. However, lots of students are afraid of asking teachers for this kind of help.

The two main obstacles in statistics students are their levels of anxiety and background (mathematical) knowledge. They must be taught or trained how to reduce high levels of anxiety influenced by statistics courses, especially by examinations and difficult lessons. Mathematics/statistics anxiety can produce smaller working memory spans and poorer overall performance in mathematics-related subjects [1]. The level of this kind of anxiety can be diminished by using behavioral in combination with cognitive psychotherapy approaches. However, this treatment needs to be professionally-monitored (e.g. by a psychologist or a well-trained teacher). Despite this notion, students can help themselves in the (at least) three ways:

1. By improving their statistical skills and increasing their knowledge of this subject (in this way, they start to feel they are more self-confident and academically effective; in turn, they will no more be as afraid of failure as before);
2. By being aware of their physiological reactions and trying to relax, thinking of some pleasant activities.
3. By starting to ask their classmates on the problems they usually encounter while learning statistics and preparing for exams (that is, obtaining social support from them).

The issue of insufficient background knowledge could be overcome by watching online tutorials on fundamental mathematical concepts, statistics and probability theory. In addition, students can ask their peers to help them or admit shortcomings of their knowledge to teachers, by expressing will to work on its improvement.

The quality of teaching materials

First, the teacher should choose an appropriate textbook of statistics. S/he can ask her/his students to pick a textbook (out of e.g. three of them) that seems enough convenient to them. In this way, student can meet their need for *autonomy* (because they can decide upon the textbook) and *competence* (teacher trusts them and allows them to employ their cognitive skills in choosing a textbook that fits their cognitive needs).

The modern textbook of statistics should include the following items:

a) Textbooks that are suitable for all students involved in statistical courses usually begin with explanations of some basic mathematical concepts (e.g. sum and product notiation; algebra, statistics, and probability symbols...).
b) Statistical concepts and techniques that are explained clearly and in detail.
c) The way (step-by-step) statistical procedures can be obtained within a specific statistical package (e.g. STATA, R, SAS, SPSS...).
d) Wide range of real-life examples (e.g. "The importance of standard deviation is evident from the following example: Our body temperature fluctuates over the day. It achieves the maximum around 5 p.m. and its minimum is usually recored around 4 a.m. In fact, its standard deviation is approximately 0.4 degrees of Celsius.").
e) Questions by which not only students' superficial knowledge is checked (e.g. "What is the standard error of the mean?"), but those which stimulate statistical reasoning (e.g. "Why is the standard error of the mean so important? Please, provide an example in which the practical value of this concept can be obvious and clear.").
f) Some exercises and tasks that are not completely done by the author of the textbook. To be more specific, its author should give students hints about coming to solution. In this way, students are encouraged to problem-solve on their own.
g) At the end of a textbook, there should be a list of most commonly used formulas and a glossary with main statistical (and probability) concepts.
h) Additionally, the author of the textbook should include some other resources in which students can read more about a topic, specific methods, and procedures... and, as a result of that, expand their statistical knowledge.

M. J. de Smith argues that it is no longer acceptable to produce a discipline-specific (or standard) textbook, because it will not meet all needs of its new users [15]. He also underlined the two main advantages of electronic formats: internal and external hyperlinks with which text can be embedded. Some authors (for instance S. K. Lwanga, C. Y. Tye, and O. Ayeni with their book: *Teaching health statistics: Lesson and seminar outlines* [9]), write and design teaching materials so that they are halfway between a textbook and a self-instructional material for students. The rationale of this approach is an attempt to reinforce students and teachers to be active participants in constructing knowledge as well as creators and maintainers of the *statistics teaching-learning loop.*

Final remarks

Statistical literacy and reasoning are not such a matter about which academic community should be concerned only. It is, in fact, an important set of skills and competencies for all the modern society. An average citizen should be able to make valid conclusions from figures in e.g. graphs of voting or census results that are heard on the news, tables that include information on the rate of unemployment or gross domestic product (GDP) and so on.

Undergraduate, graduate, and postgraduate programs in different disciplines should include statistics courses, where students can acquire main statistical concepts and procedures, learn how to use statistical packages, apply statistical knowledge and use these skills in solving real-life problems

(examples), and critically consider the results obtained by these statistical procedures. If teachers possess high levels of general mathematical knowledge, domain-specific (e.g. statistical) knowledge, pedagogical skills, social/emotional intelligence, and the ability to motivate their students, learning statistics will not be as difficult as it seems to be. If we add students' qualities (using learning strategies, low levels of anxiety, rich backgroung knowledge, and intrinsic motivation) along with the appropriate teaching materials, the process of teaching and learning statistics becomes self-motivating and produces very positive learning outcomes.

To the knowledge of this author, studies that included all of these factors have not been conducted yet. In accordance with this notion, further research should examine their predictive power for students' performance on statistical quizzes and exams. Some of them are probably better predictors than the others. However, reliabile and valid instruments that assess these factors (for instance, checklists and psychological scales) should be designed.

To sum up, the author of this article proposed a *working model* (Figure 1) that brings together the three aspects of pedagogical triad (teachers' qualities, students' traits and activities, and teaching material characteristics), to explain students' performance in the field of statistics.

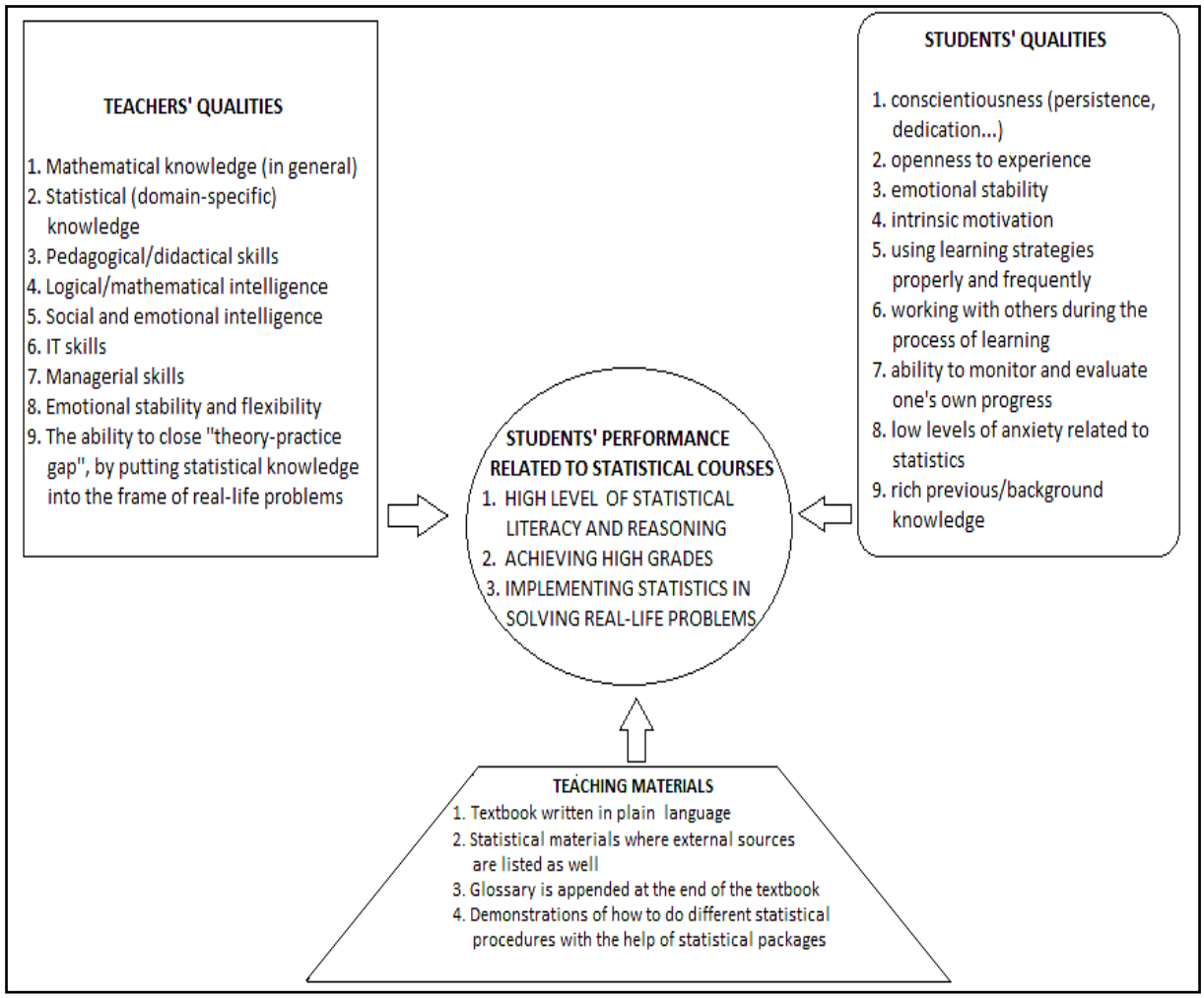

Figure 1. The working model of students' performance linked to statistical courses

As can be seen (Fig. 1), not only high grades matter, but also students' capacity to implement statistics in solving practical problems. In addition, a proper constellation of teachers' and students' qualities along with adequate teaching materials produces a high level of statistical literacy as well as very good to remarkable statistical reasoning skills. Additionally, methodological thinking should be taught together with statistical reasoning and it is being improved as course is progressing.

An attempt of the academic community to promote and reflect on teaching statistics resulted in publishing journals such as *Journal of Statistics Education* or *Statistics Education Research Journal*, and establishing organizations like *International Association for Statistical Education.* Ultimately, it should be anticipated that the bright future of this field is yet to come.

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