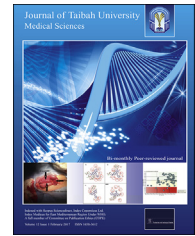




Taibah University
Journal of Taibah University Medical Sciences

www.sciencedirect.com



Review Article

Helping medical students in their study of statistics: A flexible approach

Jimmie Leppink, PhD

School of Health Professions Education, Maastricht University, Maastricht, The Netherlands

Received 29 June 2016; revised 10 August 2016; accepted 21 August 2016; Available online 11 October 2016



المخلص

يحتاج طلبة الطب خلال مرورهم بمناهجهم الدراسية إلى اكتساب المعرفة والمهارات في مجموعة متنوعة من المجالات. ويحتاج المدرسون ومصمموا الخطط التعليمية إلى دمج كل من هذه الموضوعات في المناهج الدراسية، وأن يقرروا ماذا سيتم تغطيته، وفي أي وقت، وبأي وسيلة، وأنشطة تعليمية. وحيث إنه من المتوقع من الخبراء في المجال الطبي أن يتحلوا على الأقل بالمهارات الأساسية للعمل مع المعلومات الرقمية، التي يمكن أن تنثري عملية صنع القرار في عملهم اليومي، فإن الإحصاء يُعد جزءاً لا غنى عنه من المنهج الدراسي الطبي. والإحصاء هو موضوع معقد يتميز بمفاهيم منظمة تنظيمياً هرمياً وغير حدسية. ولمساعدة طلاب الطب على تطوير فهم مفاهيم الإحصاء التي تساعدهم على فهم وإيصال المعلومات الإحصائية المتعلقة بمرضاهم، أو التي يحصلون عليها من البحوث التجريبية، فإن على المدرسين ومصممي الخطط التعليمية ترتيب تدريس الإحصاء للطلبة بحيث يتم عرضه عليهم بصورة منظمة ومتدرجة. توضح هذه المقالة تطور تعليم الإحصاء والبحوث في هذا المجال، وكيف ينطبق ذلك على التعليم الطبي وكيف يمكن لنهج مرن أن يساعد المدرسين ومصممي الخطط التعليمية على خلق بيئة تعليمية تمكن الطلبة من تنمية المعرفة والمهارات التي سيحتاجونها خلال فترات تدريبهم (الامتياز) وعملهم.

الكلمات المفتاحية: نظرية التحميل الإدراكي؛ الدعم التوجيهي؛ التعقيد؛ الإخلاص

Abstract

In the course of their curriculum, medical students must acquire knowledge and skills in a variety of domains. Teachers and educational designers need to integrate each of these topics into the curriculum and decide what to cover during which period and with which learning

materials and activities. Since medical experts are expected to have at least basic skills with numerical information that can inform decision-making in their daily work, statistics is an indispensable component of the medical curriculum. Statistics is a complex topic that is characterized by hierarchically organized and counterintuitive concepts. To help medical students develop a conceptual understanding of statistics that enables them to understand and communicate statistical information regarding patients or from empirical research, teachers and educational designers should organize their students' study of statistics such that they are guided into the topic systematically and gradually. This article outlines the evolution of statistics education and research in this area, how it applies to medical education, and how a flexible approach can help teachers and educational designers create a learning environment in which students can develop the knowledge and skills they will need during their internships and jobs.

Keywords: Cognitive load theory; Complexity; Fidelity; Instructional support

© 2016 The Author.

Production and hosting by Elsevier Ltd on behalf of Taibah University. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Introduction

During the course of their curriculum, medical students must acquire knowledge and skills in a variety of domains. Teachers and educational designers need to integrate each of these topics into the curricula and decide what to cover during which period and with which learning materials and activities.¹ Since medical experts are expected to have at least

Corresponding address: Department of Educational Development and Research, Maastricht University, PO Box 616, 6200 MD Maastricht, The Netherlands.

E-mail: jimmie.leppink@maastrichtuniversity.nl

Peer review under responsibility of Taibah University.



Production and hosting by Elsevier

1658-3612 © 2016 The Author.

Production and hosting by Elsevier Ltd on behalf of Taibah University. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>). <http://dx.doi.org/10.1016/j.jtumed.2016.08.007>

basic skills with numerical information that can inform decision-making in their daily work, statistics is an indispensable part of the medical curriculum. Statistics is a complex topic that is characterized by hierarchically organized and counterintuitive concepts. To help medical students develop a conceptual understanding of statistics that enables them to understand and communicate statistical information about patients or from empirical research, teachers and educational designers should organize their students' study of statistics such that they are guided into the topic systematically and gradually. This article outlines the evolution of statistics education and research in this area, how it applies to medical education, and how a flexible approach can help teachers and educational designers create a learning environment in which students can develop the knowledge and skills they will need during their internships and jobs.

Statistics education throughout the years

Three factors appear to underlie competence in statistics: computational aptitude, propositional knowledge, and conceptual understanding.² Where computational aptitude is about the ability to understand and use mathematical formulae, propositional knowledge and conceptual understanding refer to knowledge of statistical concepts and their interrelationships, respectively.

A shift of focus

Profiting greatly from technological advancements of the past decades, statistics education has taken a massive shift from a focus on computational aptitude to a conceptual understanding of statistics that is needed to interpret statistical information. The time that previously was allocated to learning how to perform calculations by hand is now spent on familiarizing students with statistical software that can do the computations for them. With this development, the aforementioned three-factorial model of statistical competence appears to have expanded with a fourth factor, namely that of proficiency with one or more software programmes. Whichever programme one uses, producing statistical output to address a question of interest — such as a research question in a medical study — requires knowledge of the context in which the question is formulated as well as some conceptual understanding of statistics.

Towards conceptual understanding

Unfortunately, a conceptual understanding of statistics does not come naturally. Research in the early and mid-2000s provided evidence that learning activities needed to be centred around structured learning materials that initially helped students build propositional knowledge and subsequently develop a conceptual understanding of statistics.^{3–5} Research building on those findings adds that, to introduce novice students to statistical themes, one additional step is needed, namely the provision of instructional support as either worked examples studied individually⁶ or partially worked examples or completion tasks carried out together with peers.⁷ While the structuring of learning materials and activities may in itself increase the effectiveness of lectures,⁸

when implementing that structure in, for example, a problem-based learning^{9,10} curriculum, one needs to start with worked examples or completion tasks and fade that support as students advance.¹¹ In short, when introducing students to a new statistical theme, it is best to start with worked examples of typical problems and decrease that guidance towards autonomous problem solving as students advance.¹²

The challenge of having to learn statistics

One perspective on learning that has received increasing support in the medical education field is that of cognitive load theory.^{13–15} In this theory, learning is perceived as the gradual development of cognitive schemas. When medical students are first confronted with statistics, they typically have premature cognitive schemas of the topic. Self-explanation,^{16,17} argumentation,^{18,19} and peer-to-peer explanation^{7,20} of learning materials are processes that may facilitate schema development if the appropriate amount of instructional guidance is provided.^{6,7,11,12,21,22}

Three dimensions in the design of education

In any topic about which we intend to design learning tasks, three dimensions must be considered: *task fidelity*, *task complexity*, and *instructional support*.^{1,23}

In the topic of medicine, the *fidelity* dimension extends all the way from textual medical descriptions through different types of simulations to real patients in an internship and subsequent job.²⁴ Analogously, in the context of statistics, the fidelity dimension extends all the way from textbook descriptions of statistical concepts and simple computer exercises involving these concepts to the analysis and production of brief reports and small papers, and subsequently a thesis and/or larger paper, which includes communication of statistical information.

The *complexity* dimension revolves around the number of information elements in a learning task. The elaborateness of our cognitive schemas influences what we perceive as an information element. That is, where novices may perceive a myriad of information elements that need to be processed simultaneously to make sense of the information, more advanced learners have to process fewer information elements because they can activate their cognitive schemas.^{13–15} In other words, the intrinsic complexity of particular information as perceived by the individual learner decreases as one's cognitive schemas become more elaborate. To neither underload²⁵ nor overload²⁶ learners, complexity of information, as defined by the number of information elements in a learning task, should be tailored to learners' prior knowledge or ability level.²⁷

Finally, the *support* dimension addresses the way in which information is presented. The more our cognitive resources are needed to address how information is presented, the less available they will be to deal with the intrinsic content or complexity of information.²⁸ Thus, education must be designed such that information is presented to learners in a way that requires only a minimum of their cognitive resources.^{15,24} The most straightforward way to reach that goal is to introduce medical students to a novel statistical

topic with high instructional support and fade that support as their learning advances.

Minimizing engagement in ineffective cognitive processes

Apart from the trajectory of fading support from worked examples through completion tasks to autonomous problem solving, we have to bear in mind three additional issues when choosing how to design instructional support. Altogether, these aspects constitute a best practice in minimizing the extent to which allocating cognitive resources to deal with presented information hinders students from learning from the intrinsic content of information.

Firstly, especially when introducing a new topic, we should avoid situations where students must split their attention between multiple sources across space or time, especially if we can provide a single integrated source of information.²⁹ For instance, suppose that to understand or solve a problem, students have to scroll back and forth between parts of a webpage. This activity requires students to process information from one part of the page while holding information from another part of the page. Consequently, students may need to devote their cognitive resources to dealing with the unfavourable presentation of the information to the extent that the remaining resources may be insufficient for understanding or solving the problem. Likewise, if students attending a practical session receive a verbal explanation of how to use a particular statistical tool too long before they actually use it, they may have limited cognitive resources available to process the information provided during that time interval because they are trying not to lose the information on how to use the tool.

Secondly, some concepts simply should be presented visually rather than verbally. For instance, a teacher trying to describe a normal distribution in words requires students to process a considerable amount of verbal information to understand what the described distribution looks like. Although presenting specific verbal descriptions along with a visual depiction of a normal or bell-shaped distribution may facilitate the understanding of the visual depiction, omitting the latter is more likely to hinder learning. With the advent of YouTube and other media, the number of videos that simulate specific concepts in a real-life context is growing exponentially. Of course, we cannot expect students who are not yet familiar with concepts to be learnt to judge which videos are of good quality and which ones are not (unfortunately, there is quite some material online that is not of good quality). However, this is where teachers and curriculum developers come in; they can select good materials and integrate them into a programme.

Thirdly, redundancy should be avoided. If, for instance, a diagram speaks for itself, verbal descriptions may well be omitted as they likely will require students to process extraneous information that obstructs rather than facilitates their understanding of the diagram.²⁴ Likewise, instructional support in the form of worked examples or completion tasks may be beneficial to students when introduced to a new topic but becomes redundant once students advance.^{21,22}

Core questions in curriculum design

Various studies have provided support for the assumption that the effectiveness of instruction depends, to a considerable degree, on assessment criteria in a course or curriculum.^{8,27} That is, as long as the boundaries of underload and overload are avoided, more challenging learning activities and assessment criteria may stimulate learning. Teachers and educational designers need to integrate the topic of statistics into the medical curriculum and decide what to cover during which period and with which learning materials and activities.¹ In this process, student heterogeneity in learning pace must be taken into account and – to stimulate students' engagement – instruction must therefore be differentiated accordingly.

Integration

To integrate the topic of statistics into the curriculum, one needs to have clear end terms of what students are expected to master at the end of a curriculum and after completing a particular course within that curriculum. Given the hierarchical structure of occasionally counterintuitive concepts, learning statistics takes time. Therefore, to cram all statistics in a single couple-of-weeks course is unlikely to enable students to develop the conceptual understanding of statistics needed for the appropriate use of and communication about statistical information. Rather, such an approach may stimulate students' preconceptions that statistics is an unavoidable evil that one should pass to continue with actual medical content. Carefully spacing statistical learning activities throughout the curriculum may reduce the latter and actually stimulate students to perceive statistics as an indispensable part of our information society and of the medical curriculum and profession.

What to cover in what period?

Which statistical topics to cover and in what detail should be defined by the end terms of the curriculum and coursework within the curriculum. The hierarchical organization of statistical concepts should then determine the order in which these topics are covered. For example, one cannot expect students to have a clear understanding of Pearson's correlation coefficient without any understanding of the following concepts upon which it is based: arithmetic mean, standard deviation, covariance, and standardization. In other words, until students understand these more basic concepts, initial learning activities should revolve around these concepts before covering Pearson's correlation coefficient. In terms of complexity, Pearson's correlation coefficient comprises all information elements encountered in the concepts upon which it is based. In subsequent levels, single and multiple linear regression – with all underlying assumptions, types of correlations, types of regression coefficients, and more – cannot be grasped until students understand all of the aforementioned concepts.

How much time to allocate to each of the aforementioned topics is a question that is preferably addressed by a multi-disciplinary team consisting of medical experts, educationists, and statisticians. Through this composition of

disciplines, balanced compromises may be found between ‘too much’ and ‘too little’ statistics in the curriculum. However, expectations that an understanding of key statistical concepts needed for medical practice can be reached in just a couple of weeks cannot yet be anchored in empirical reality.

Selecting learning materials

The former questions naturally lead to another question, namely how to select learning materials and activities for each of the topics (e.g., basic concepts, Pearson’s correlation coefficient, single and multiple regression), and define the space in which one can operate when addressing this question. This space is further defined by the level of fidelity at which learning takes place: initial study of statistical concepts through textbooks and basic computer tasks requires different learning materials than learning how to use these concepts in reports or theses. However, since the aim of statistics education in a medical context is to help students develop a conceptual understanding of statistics, one should carefully consider how many mathematics or programming skills to include in statistical coursework. While covering basic formulae for standard deviation or an arithmetic mean may facilitate one’s understanding of these concepts and their relation (i.e., the standard deviation is a measure of dispersion around the arithmetic mean), covering more advanced mathematics may distract from the actual aim of conceptual understanding. With regard to programming skills (required for some programs), if the time to teach statistics is limited, we need to carefully consider if we really want to sacrifice part of that time to teaching programming skills that are not essential to developing a conceptual understanding of statistics.

A flexible approach to statistics education

The aforementioned guidelines and suggestions, which are based on a large body of empirical research and theoretical review, can be summarized in the model presented in Table 1.

Start with textbook and simple computer exercises

Firstly, start with high support (worked examples, avoiding split attention) on textbook-style and simple computer exercise learning tasks that involve basic concepts – including the arithmetic mean, standard deviation, and standardization – and move to autonomous performance

(problem solving) through completion tasks. Next, repeat this process of working from high to low support for covariance of and correlation between variables, concepts that comprise more basic concepts (e.g., understanding Pearson’s correlation coefficient r requires an understanding of the concepts of mean and standard deviation). Once the transition from worked example(s) to autonomous performance has been completed for covariance and correlation, it is time to cover simple and multiple regression (and perhaps analysis of variance/analysis of covariance) in the same way. For retrieval and knowledge consolidation, it is important to embed each of these facets in a medical context. This will also make it easier for students at the next stage: using the cognitive schemas acquired with textbook and simple computer exercises to analyse and produce brief reports and small papers which present statistical information on a medical topic.

An integration of statistical and medical knowledge in medical coursework

An easy way to integrate statistics into medical coursework is to incorporate these brief reports and small papers as assignments in courses on medical subjects (e.g., anatomy, cardiology, radiology). This way, students can gain knowledge on a medical subject and practice with analysing and reporting statistical information in a context that is natural and interesting to them. Moreover, this approach can prepare students for the practice in which they will be expected to be capable of writing a thesis or larger paper that presents statistical information. Again, the sequential order of going from basic concepts to more advanced concepts (that comprise the more basic concepts) and fading instructional guidance from worked examples to autonomous performance through completion tasks provides a systematic and gradual approach not only at the level of textbook and simple computer exercises but for the analysis and production of brief reports and small papers, and subsequently theses and/or larger papers, as well. Even if students have practiced using simple and multiple regression in textbook and simple computer exercises, having them analyse or produce a report or paper that presents outcomes of regression analysis may be excessive without having them practice with reports and papers on correlation and more basic concepts first. At the same time, students who are comfortable with correlation and more basic concepts may still make mistakes in regression analysis. In other words, proficiency in reporting on correlation and more basic concepts is a necessary but not sufficient condition for a

Table 1: A flexible approach to statistics education.

Topic	Basic concepts such as mean, standard deviation and standardization			Covariance and correlation coefficients (e.g., Pearson’s r)			Simple and multiple regression (and perhaps analysis of [co]variance)		
Textbook and simple computer exercises	WE	CT	AP	WE	CT	AP	WE	CT	AP
Analysis and production of brief reports and small papers	WE	CT	AP	WE	CT	AP	WE	CT	AP
Theses/larger papers with statistical information	WE	CT	AP	WE	CT	AP	WE	CT	AP

WE = Worked Example, CT = Completion Task, AP = Autonomous Performance (problem solving).

student's ability to communicate findings of a regression analysis.

Spacing of statistical content can facilitate integration

As mentioned previously, there is little reason to assume that compiling all statistics in one multi-week course for students results in any conceptual understanding of statistics for two reasons. Firstly, the development of cognitive schemas of hierarchically organized and counterintuitive concepts takes time. Secondly, the approach of cramming information into a short timeframe is unlikely to result in any clear understanding by students about why statistics could be a useful tool throughout their studies and at the workplace. The starting assumption should be that if we fail to provide students with examples of how statistics can be useful to them, they might only approach the topic with dislike.

By spacing statistical learning activities over different courses and skills training sessions throughout the curriculum, students are given time to digest essentially complex concepts and meanwhile encounter opportunities to apply their understanding. The latter can manifest in a critical evaluation of articles presenting arguments based on statistical information as well as in writing short reports on cases or small studies that involve statistical information. This creates a setting in which learning statistics – or any other topic under consideration – becomes a journey or story in which different facets form anchored narratives.

To ensure that each of the narratives is well anchored, students need to be given sufficient time to practice concepts learnt at each of the subsequent fidelity levels. For example, reading about an interpretation of a correlation coefficient in a textbook does not imply that one can apply it in a practical setting. Simultaneously, being confronted with correlation coefficients in a practical setting without having ever seen them before may not result in any learning because there are many information elements to process in that setting. One may not have sufficient cognitive resources available for learning about correlation coefficients. When dealing with correlation coefficients in textbooks and simple computer exercises first, one can apply his/her understanding of correlation coefficients by activating his/her cognitive schema and meanwhile use his/her cognitive resources to address the other information elements in the practical setting. This practice also underlines the importance of selecting learning materials and activities that prepare students for how to interpret and communicate statistical information in a practical medical context.

Flexibility in prior knowledge, pace, and expected end level

Learning can be expected to be most effective when students engage in learning activities within their zone of proximal development.³⁰ The zone of proximal development represents an area of learning where one cannot yet solve problems autonomously but can do so with the help of an expert or in collaboration with more capable peers. Thus, problems should be neither too easy nor too complex. Note that different students can be in different zones of proximal development at a given time: their prior knowledge may vary substantially, and the same applies to

their interest in the topic and the pace at which their learning advances. Ignoring these differences by adopting a one-size-fits-all approach to which all students are expected to adhere can hinder learning among a majority of students.^{6–8,11,12,21–23} By having learning materials available in different levels of support, complexity, and fidelity, we can allow for differences in prior knowledge and learning pace, and – as such – optimize learning across the full range of prior knowledge and learning pace.^{1,23} In other words, the support-complexity-fidelity framework provides a three-dimensional representation of Vygotsky's two-dimensional zone of proximal development.

The previously described framework has at least two practical implications. Firstly, teachers can provide students with high-support, low-complexity, low-fidelity tasks first and assess which students move faster or slower and therefore need different timing in fading support and/or in moving to the next complexity or fidelity level. Secondly, considering that increasing numbers of master's programmes are taken by students who – given their prior trajectories – differ substantially from each other in terms of prior knowledge, pace, or ambitions, more advanced students could start with somewhat more advanced materials as they may have passed more basic work already in previous training. Moreover, students who intend to become more involved in research may want to pursue more stringent goals in their study of statistics than their colleagues who are not interested in such a path. In this context, a one-size-fits-all approach would require too much from a considerable portion of students and/or hinder more advanced and more interested students from progressing.

Generalizability to other health profession programs

Although this article uses the medical domain as an example, the empirical research reviewed in this article also included health college students as well as students in psychology, business, and other domains. Moreover, inter-professional coursework such as interdisciplinary master's programmes is becoming more and more common. The principles of flexibility in prior knowledge, pace, and expected end level offered by the model presented in [Table 1](#) also applies to this inter-professional coursework. Master's programmes in education for health professions may, for instance, attract medical and health practitioners, educationalists, psychologists, and other professionals and may offer different specializations such as clinical and research tracks. For students on the research track, [Table 1](#) may be expanded to one or more additional topics depending on the needs and goals of the track and individual students therein. Candidate topics then include path analysis, mixed-effects analysis, and latent variable models such as factor analysis and structural equation modelling. Of course, since these topics require a solid understanding of all topics in [Table 1](#), these areas would need to be covered after regression analysis, following the same approach of fading instructional guidance (worked examples – completion tasks – autonomous performance) and increasing fidelity (textbook and simple computer exercises – analysis and production of brief reports and small papers – thesis/larger papers with statistical information) as the topics in [Table 1](#).

In conclusion, although differentiating education may require more planning and preparation time on the part of teachers and curriculum developers, the approach is more likely than a one-size-fits-all approach to sustain student engagement, facilitate conceptual understanding, provide tailored support to students as necessary, and produce professionals with the knowledge and skills to make sense of statistical information and make informed, evidence-based decisions.

Sources of support in the form of grants

Netherlands Organisation for Scientific Research (NWO), Programme Council for Educational Research (PROO) Scaffolding self-regulation: effects on the acquisition of domain-specific skills and self-regulated learning skills (grant number: 411-12-015).

Conflicts of interest

The author has no conflict of interest to declare.

Author contribution

The author testifies that he qualifies for authorship and has checked the article for plagiarism. He conceived, designed, and carried out the literature study, and wrote the full manuscript as well as the revised version of the manuscript addressing the reviewers' issues raised with the initial version of the manuscript. The author critically reviewed and approved both the initial manuscript (sent out for review) and the revised version of the manuscript (in which the reviewers' issues raised with the initial version of the manuscript have been addressed). The author is responsible for the content and similarity index of the manuscript.

Jimmie Leppink is currently a postdoctoral researcher, consultant for and teacher in quantitative methodology and analysis, and data manager for the School of Health Professions Education, Maastricht University, the Netherlands. His research focuses on adaptive approaches to instruction and assessment, cognitive load theory and measurement, and multilevel analysis of educational data.

References

- Leppink J, Duvivier R. Twelve tips for medical curriculum design from a cognitive load theory perspective. *Med Teach* 2016; 38: 669–674. <http://dx.doi.org/10.3109/0142159X.2015.1132829>.
- Huberty CJ, Dresden J, Bak B. Relations among dimensions of statistical knowledge. *Educ Psychol Meas* 1993; 53: 523–532.
- Broers NJ. Selection and use of propositional knowledge in statistical problem solving. *Learn Instr* 2002; 12: 323–344.
- Broers NJ, Imbos T. Charting and manipulating propositions as methods to promote self-explanation in the study of statistics. *Learn Instr* 2005; 15: 517–538.
- Broers NJ, Mur MC, Budé L. Directed self-explanation in the study of statistics. In: Burrill G, Camden M, editors. *Curricular development in statistics education*. Voorburg, the Netherlands: International Statistics Institute; 2005. pp. 21–35.
- Leppink J, Broers NJ, Imbos T, Van der Vleuten CPM, Berger MPF. Self-explanation in the domain of statistics: an expertise reversal effect. *High Educ* 2012; 63: 771–785.
- Leppink J, Broers NJ, Imbos T, Van der Vleuten CPM, Berger MPF. Prior knowledge moderates instructional effects on conceptual understanding of statistics. *Educ Res Eval* 2012; 18: 37–51.
- Leppink J, Broers NJ, Imbos T, Van der Vleuten CPM, Berger MPF. The effectiveness of propositional manipulation as a lecturing method in the statistics knowledge domain. *Instr Sci* 2013; 41: 1127–1140.
- Barrows HS. A specific, problem-based self-directed learning method designed to teach medical problem-solving skills, and enhance knowledge retention and recall. In: Schmidt HG, De Volder ML, editors. *Tutorials in problem-based learning*. Assen, the Netherlands: Van Gorcum; 1984.
- Barrows HS. Problem-based learning in medicine and beyond: a brief overview. In: Wilkerson L, Gijsselaers WH, editors. *New directions for teaching and learning*, vol. 68. San Francisco: Jossey-Bass Publishers; 1996. pp. 3–11.
- Leppink J, Broers NJ, Imbos T, Van der Vleuten CPM, Berger MPF. The effect of guidance in problem-based learning of statistics. *J Exp Educ* 2014; 82: 391–407.
- Leppink J, Paas F, Van Gog T, Van der Vleuten CPM, Van Merriënboer JJG. Effects of pairs of problems and examples on task performance and different types of cognitive load. *Learn Instr* 2014; 30: 32–43.
- Sweller J. Cognitive load during problem solving: effects on learning. *Cogn Sci* 1988; 12: 257–285.
- Sweller J, Ayres P, Kalyuga P. *Cognitive load theory*. New York: Springer; 2011.
- Sweller J, Van Merriënboer JJG, Paas F. Cognitive architecture and instructional design. *Educ Psychol Rev* 1998; 10: 251–296.
- Atkinson RK, Renkl A, Merrill MM. Transitioning from studying examples to solving problems: effects of self-explanation prompts and fading worked-out steps. *J Educ Psychol* 2003; 95: 774–783.
- Berthold K, Renkl A. Instructional aids to support a conceptual understanding of multiple representations. *J Educ Psychol* 2009; 101: 70–87.
- Fischer F. Gemeinsame Wissenskonstruktion – Theoretische und methodologische Aspekte [Joint knowledge construction – theoretical and methodological aspects]. *Psychol Rund* 2002; 53: 119–134.
- Knipfer K, Mayr E, Zahn C, Schwan S, Hesse FW. Computer support for knowledge communication in science exhibitions: novel perspectives from research on collaborative learning. *Educ Res Rev* 2009; 4: 196–209.
- Kramarski B, Dudai V. Group-metacognitive support for online inquiry in mathematics with differential self-questioning. *J Educ Comp Res* 2009; 40: 377–404.
- Kalyuga S, Ayres P, Chandler P, Sweller J. The expertise reversal effect. *Educ Psychol* 2003; 38: 23–31.
- Kalyuga S, Chandler P, Tuovinen J, Sweller J. When problem solving is superior to studying worked examples. *J Educ Psychol* 2001; 93: 579–588.
- Leppink J, Van den Heuvel A. The evolution of cognitive load theory and its application to medical education. *Perspect Med Educ* 2015; 4: 119–127.
- Van Merriënboer JJG, Sweller J. Cognitive load theory in health professions education: design principles and strategies. *Med Educ* 2010; 44: 85–93.
- Young MS, Stanton NA. Attention and automation: new perspectives on mental underload and performance. *Theor Issues Ergon Sci* 2002; 3: 178–194.
- Kalyuga S, Hanham J. Instructing in generalized knowledge structures to develop flexible problem solving skills. *Comp Hum Behav* 2011; 27: 63–68.
- Lafleur A, Côté L, Leppink J. Influences of OSCE design on students' diagnostic reasoning. *Med Educ* 2015; 49: 203–214.

28. Leppink J, Van Gog T, Paas F, Sweller J. Cognitive load theory: researching and planning teaching to maximize learning. In: Cleland J, Durning SJ, editors. *Researching medical education*. Chichester: John Wiley & Sons; 2016. pp. 207–218. chapter 18.
29. Sweller J. Element interactivity and intrinsic, extraneous, and germane cognitive load. *Educ Psychol Rev* 2010; 22: 122–138.
30. Vygotsky LS. *Mind in society: development of higher psychological processes*. Harvard University Press; 1978.

How to cite this article: Leppink J. Helping medical students in their study of statistics: A flexible approach. *J Taibah Univ Med Sc* 2017;12(1):1–7.