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Statistical Education in the 21st Century: a Review of Challenges, Teaching Innovations and Strategies for Reform

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Abstract

Over the past few decades there has been a large amount of research dedicated to the teaching of statistics. The impact of this research has started to change course content and structure, in both introductory and advanced courses for statisticians and those from other disciplines. In the light of these changes future directions in the teaching and learning of statistics must take into account new innovative pedagogical instructions, educational technologies and the abundance of Web resources that are now available. This article examines different aspects of currently identified challenges in the teaching and learning of statistics and gives an overview of useful strategies and innovations for developing research-based statistics courses in the context of recommendations for reforms, outlining the place of information technology within this framework. The article presents a review of the literature on the topic of statistics education and gives instructors a set of guidelines for generating new and effective teaching material. The summarised recommendations incorporate many innovations employed in a variety of successful statistics classes today. The review is complemented by a collection of statistics related online resources currently available on the Web.

1. Introduction

Over the last twenty years there has been increasing attention given to the teaching and learning aspects of statistics education (Garfield, 1993; Becker, 1996; Moore, 1997; Garfield, 1995; Garfield and Ben-Zvi, 2008; Garfield and Ben-Zvi, 2007). It is widely recognised that

statistics is one of the most important quantitative subjects in a university curriculum (Watson, 1997). It is also acknowledged that teaching statistical courses is challenging because they serve students with varying backgrounds and abilities, many of whom have had negative experiences with statistics and mathematics (Garfield, 1995). Perhaps most critical is the fact that these courses affect life-long perceptions of and attitudes towards the value of statistics for many students, and hence many future employees, employers and citizens.

Statistics education research over the last decade has emphasised the need for reform in the teaching of statistics with a growing body of research in this area. An increasing number of scientific publications devoted to this topic indicates that statistics education is developing as a new and emerging discipline (Garfield and Ben-Zvi, 2008). However, research on the teaching and learning of statistics remains disconnected, fragmented, and difficult to access (Zieffler, Garfield, Alt, Dupuis, Holleque, and Chang, 2008). This paper reviews the recent literature related to statistics pedagogy and the current thinking of leading educators in the field. We attempt to outline the currently identified problems and challenges in statistical education and summarise the recommendations and techniques that we consider to be potentially useful in the teaching and learning of statistics.

This article is aimed primarily at instructors of applied statistics courses at the tertiary level who are interested in the pedagogical research and resources available to help them improve their teaching of statistics. The purpose of the paper is (i) to review the current challenges of statistics teaching in the UK and other countries; (ii) to highlight the teaching strategies and learning theories proven to be useful in statistics education; and (iii) to provide a systematic overview of statistics Web resources to help statistics instructors to implement Internet technology into a wide range of courses.

The article essentially comprises of three sections and proceeds in the following manner. Section 2 gives an overview of the current state of statistics teaching summarising problems identified in the recent pedagogical literature. Section 3 addresses strategies for reform-based teaching of statistics with a special focus on the use of technological resources available in today's information driven society. Section 4 emphasises the potential of the Internet for teaching and learning statistics and reviews statistics-related Web resources. To complement the overview of Web enhanced learning we provide an annotated list of useful online resources for teaching statistics which can assist in designing course content and delivery.

2. Current Challenges of Teaching Statistics

Despite the widespread emphasis on reform in the teaching of statistics and the increase in papers on statistics education in the research literature, statistics is still viewed as a discipline with a need for significant improvement in how students are educated (Garfield and Ben-Zvi, 2008). Over the past few decades researchers and educators have been trying to understand the challenges in learning and teaching statistics and to identify the changes that are needed in the training of future statisticians. However, it seems that there is still a gap between the research and practice of teaching statistics. Not all statisticians are aware of the full learning potential of their discipline which can be reached by using research-based strategies. In an attempt to improve the teaching and learning of statistics at the tertiary level, we list the identified

challenges of statistics education. In Table 1 we summarise the current problems in teaching and learning statistics based on the relevant research. The problem areas are classified into three domains: (1) teaching and learning of statistics as a discipline; (2) statistical literacy and communicating statistics; and (3) statistics as a profession in the UK and other countries. Each of these domains is examined in the following sections. The list in the table is supported by relevant references which are representative and not exhaustive.

Table 1. List of Identified Problems in Teaching Statistics

Author	Identified Problems
I. Teaching and Learning of Statistics as a Discipline	
Garfield (1995); Allen, Folkhard, Lancaster, Sherlock & Abram (2012)	Focus on mathematical and mechanical aspects of knowledge. It results in students not being empowered to apply statistical content knowledge to solve problems arising from a specific context.
Gal & Ginsburg (1994); Garfield (1995); Verhoeven (2006)	'Maths-phobia', 'statistics anxiety', negative attitude towards statistics, pre-dispositions against statistics, lack of interest displayed in students from other disciplines.
Garfield (1995); Garfield & Ben-Zvi (2007)	Ideas of probability and statistics are very difficult for students from other disciplines to learn.
Garfield & Ahlgren (1988); Batanero, Godino, Green & Holmes (1994)	Deficiencies in basic statistical knowledge and mathematical background of students. Inadequacies in prerequisite mathematics skills and abstract reasoning.
Verhoeven (2006); Smith & Staetsky (2007); Meng (2009)	Statistics courses given as 'service teaching' are often taught with no link to the subject area, or by subject-specific specialists who are not statisticians.
Garfield (1994); Gal & Garfield (1997); Garfield & Gal (1999)	There is a need for alternative approaches to assessment. Traditional assessment techniques do not provide valid and reliable measurements on important student outcomes such as statistical reasoning.
Zieffler et al. (2008)	Lack of graduate programs and courses to train statistical educators.
II. Statistical Literacy and Communicating Statistics	
Gal (2002); Schield (2004); Verhoeven (2006)	Lack of statistical literacy and inability of students to apply statistician everyday life.
Garfield and Gal (1999)	There is a need for assessment methods to evaluate the interpretive skills and statistical literacy in students as future consumers of data.
Watson (1997); Gal (2002)	Deficiency in tools to assess statistical thinking and statistical literacy of the population and the ability to make sense of published results from studies and surveys reported in the media or in a workplace context.
Spiegelhalter & Riesch (2008); Spiegelhalter (2008); Goldacre (2008)	Incorrect media representation of issues of risk. Social amplification of risk in the media. Journalists' misunderstanding of statistical issues in academic press releases.

III. Statistics as a Profession in the UK and Other Countries	
Statistics at Australian Universities (2005); Australian Academy of Science (2006); Smith & Staetsky (2007)	Statistics is declining as a taught subject, recruitment of students and junior faculty is becoming increasingly challenging.
Kettenring, Lindsay and Siegmund (2003); Statistics at Australian Universities (2005); IRMS (2010)	Relatively few PhD students are attracted to the discipline. In some countries the profession cannot meet demand with domestic candidates, a high proportion of PhD students come from foreign recruitment.
Roberts' Review (2002); Kettenring, Lindsay and Siegmund (2003); Statistics at Australian Universities (2005); Australian Academy of Science (2006); Forbes (2008).	Shortage of statisticians in the workplace with increasing numbers of retirements reducing senior staff numbers.
Kettenring, Lindsay and Siegmund (2003); IRM (2004); Australian Academy of Science (2006); Forbes (2008); Brown and Kass (2009); IRMS (2010)	Shortage of statistical staff in universities. Significant difficulties in recruitment, filling vacant positions and retention of qualified personnel (in the mathematical sciences including statistics) are apparent (and are likely to worsen in Australia and the UK).
IRM (2004); IRMS (2010)	In the UK specifically, there are problems in ensuring adequate research staff and leaders for future UK statistics research. There is a potential risk of losing the UK's high international stature in statistics.

2.1 Teaching and Learning of Statistics as a Discipline

In the age of "information explosion" there is a critical need for statistically educated citizens. Traditional statistical education has focused on developing knowledge and on methodological skills, procedures, and computations. It was assumed that students would add value to the subject in the process of learning. But this approach has not worked and does not lead students to reason or think statistically (Snee, 1993).

Over the years there has been strong anecdotal evidence that students at university develop antipathy towards statistics and, typically, students at all levels lack interest in learning when taking introductory statistics courses. During the last decade there has been significant concern expressed about the future of statistics. Cox (1997), Moore (1997), Smith and Staetsky (2007) raise many different issues about statistics as a discipline including the need for changes in statistics pedagogy, statistical course content and format. des Nicholls (2001) points out that while at the tertiary level the last five decades have seen significant advances in theoretical aspects of statistics, unfortunately, to some degree this has been at the expense of appropriate training of occasional users of statistics. This is closely related to the problematic area of service teaching statistics to non-specialists which is addressed by many statistics education researchers (see e.g. Allen, Folkhard, Lancaster, Sherlock, and Abram, 2012).

The growing body of research into statistics education as a distinct discipline has provided us with a vast amount of literature focused on improving the teaching and learning of statistics and probability, and on reform-oriented pedagogy in the area of teaching statistics. Leading statistics educators have raised issues of concern in statistical education and urged a reform of

statistics instruction and curriculum based on strong synergies among content, pedagogy, and technology (see e.g. Garfield and Ahlgren, 1988; Garfield, 1995; Moore, 1997). In Table 1 we emphasise difficulties that have been identified in explaining why statistics is a challenging subject to learn and teach. The challenges listed in Table 1 show that there is a recognised need for continuing review of the teaching and learning process in this complex domain of teaching.

2.2 Statistical Literacy and Communicating Statistics

Our society has entered into an age of information where people need to be statistically literate not only in the workplace but also in their everyday life. There is a growing recognition of the importance of statistical literacy across different aspects of our daily lives and in the past few years statistics educators have emphasised the place of statistical literacy in statistics education reforms (see e.g. Gal, 2002; Ben-Zvi and Garfield, 2004). One of the implications of this was a movement to socially-based curriculum frameworks and towards applications-based approaches that teach students to think critically about social situations in which data are used, sometimes referred to as applying *statistical literacy*. The term statistical literacy has often been used in recent literature. Among numerous definitions of statistical literacy, perhaps the most cited is one by Wallman (1993) in her presidential address to the American Statistical Association:

"Statistical Literacy is the ability to understand and critically evaluate statistical results that permeate our daily lives -- coupled with the ability to appreciate the contributions that statistical thinking can make in public and private, professional and personal decisions."

These ideas have led to calls for an increased emphasis on statistical literacy. Gal (2002) proposes a conceptualisation of statistical literacy and describes its key components. Gal's statistical literacy model comprises two broad interrelated components; namely: (1) a knowledge component which consists of five cognitive elements: literacy skills, statistical knowledge, mathematical knowledge, context knowledge, and critical questions; and (2) a dispositional component which consists of three related but distinct concepts; namely: critical stance, beliefs and attitudes. One way of addressing the measurement and assessment of developing statistical literacy skills was proposed by Watson (1997). She suggested that the skills required to interpret stochastic information presented in society can be represented in a three-tiered hierarchy with increasing sophistication: a basic understanding of probabilistic and statistical terminology; an understanding of statistical language and concepts when they are embedded in the context of wider social discussion; and a questioning attitude when applying concepts to contradict claims made without proper statistical foundation. These authors and many other educational researchers (see e.g. Rumsey, 2002; Gal, 2003; Schield, 2004) argue that the topic of statistical literacy should be a staple item on the syllabus of an introductory statistics course.

Part of being statistically literate is the ability to discuss personal understandings of data, reactions to data, and concerns over conclusions and to communicate about statistical information (Gal, 2002). The statistical community emphasises that educated citizens should understand basic statistical concepts, and interpret and critically evaluate statistical messages

so that they can detect any misuse of statistics by policy makers, physicians and others. At the same time, associated with statistical literacy issues is the ability to communicate the relevance and importance of statistics to non-statisticians. The ability to communicate statistics evidence is identified as an important theme in the connection between statistics and the outside world and is a major problem for the profession. Greenfield (1993), addressing the question of communicating statistics, says that a change of culture is needed in how technical information is communicated to practitioners and the public in such a way that they can use and understand it. The best way to further statistical literacy in the world is to educate both the consumers of statistics and those who present statistical facts to the public.

There are specific advantages of being statistically literate for different groups in society. The media can be vulnerable to manipulation with statistics which are often spun for commercial or political goals (Goldacre, 2008). Politicians and other decision makers face similar pressure from a commercial and ideological stance and frequently need to evaluate competing statistical evidence (Blastland and Dilnot, 2008; Hand, 2009). Risk and uncertainty influence society in many ways and are key components in public debate in an evidence-based society (Lancaster, 2010). Translating statistics and risk in a readily understandable form is crucial for effective scientific and public communication (Spiegelhalter and Riesch, 2008). Today we see a large number of publications bringing to the public the message about misleading statistics, from the classic book by Huff (1954) which presents various examples, to the recent BBC series by Michael Blastland *Go Figure: Seeing stats in a different way* (2008 – March 2012, http://www.bbc.co.uk/news/magazine-17560252) about the everyday use of statistics. Research has shown that people's perception of statistics is vulnerable to different types of manipulation, and this becomes particularly relevant where health issues are concerned. Recent publications by Edwards, Elwyn, Covey, Matthews and Pill (2001), Gigerenzer, Gaissmaier, Kurz-Milcke, Schwartz and Woloshin (2007), and Lipkus (2007) reflect the need for training statisticians to communicate their findings more effectively. They provide comprehensive and useful overviews of this issue, in particular concerning communicating risk to the public. They also give effective examples for class discussions on the topic of inappropriate use of statistics.

The recognised urgent need to improve statistical literacy is reflected in a wide range of recent activities. We list here some initiatives that have been carried out across the world to promote statistical literacy.

- The International Statistical Literacy Project (ISLP) is dedicated exclusively to the promotion of statistical literacy. Its mission is "*to support, create and participate in statistical literacy activities and promotion around the world".* The work of the ISLP, since its foundation in 1991, is discussed in Sanchez et al. (2011).

- The Royal Statistical Society (RSS) 10-year statistical literacy campaign *getstats* was launched on October 20, 2010, the first United Nations World Statistics Day. It has the ambitious goal "*to build statistical understanding across society, ensuring that we all get the most out of data*". The project is notable for its scope - it is targeted at the public, schools and universities, elected representatives, business and industry and the media.

- The *Journal of the International Association for Official Statistics* devoted a special issue (Volume 27, Numbers 3, 4, 2011) to "Statistics Literacy" contributing to the understanding of statistics and promoting statistical literacy. The 10 articles in this issue cover a framework for statistical literacy, innovative teaching methods and programs aimed at improving statistical literacy.

- Programs of government National Statistical Offices (NSOs) developed with the purpose of increasing the level of statistical literacy of the public. Some of these are award winning programs, like Statistics Canada (Townsend, 2008) and Statistics Portugal (Campos, 2008). The projects comprise different components including education outreach programmes, online resources, and a vast quantity of available official statistical information placed at the disposal of the students. The successful outreach programmes of different countries are described in the online book *Government Statistical Offices and Statistical Literacy* produced by the ISLP (Sanchez (Ed.), 2008). The chapters of the book summarise the NSOs efforts and their programs in detail.

- *CensusAtSchool* is another international project currently carried out in the UK, Australia, Canada, Ireland, Japan, New Zealand, South Africa and the US. It was started in 2001 in the UK by the RSS and the Office for National Statistics. The project provides access to a large amount of data about the participating learners, with corresponding learning and teaching resources (Davies, 2011).

- *Sense about Science* is a UK organisation that aims to promote good science and evidence in public debates. Recently they produced the *Making Sense of Statistics* booklet which is aimed at politicians and contains short contributions from statisticians, journalists and scientists with tips on how to make sense of statistics and avoid common pitfalls.

- Another initiative aimed at reaching decision makers is the "Statistics policy" page (http://www.parliament.uk/topics/Statistics-policy.htm) at the UK Parliament web site. The House of Commons Library has produced a series of statistical literacy guides aimed at Members of Parliament and their staff.

There have also been a number of initiatives aimed at working with the media. The media is the main way that the general public "consume" statistical information. Work targeting this sector includes praising the best of statistical journalism and highlighting the worst, establishing relationships between statistical agencies and journalists, and providing guidance and formal courses.

- Web site www.morenumerate.org is an initiative from within the media. It is aimed at improving the use of numbers and evidence by news writers.

- The BBC's *More or Less* radio programme (http://www.bbc.co.uk/programmes/b006qshd) regularly takes an in-depth look at the

use and abuse of numbers and statistics in the media, political debate, the news and everyday life, alongside interviews with some of the leading figures in the world of numbers.

- Statistics Canada's media outreach programme includes regular meetings between their media officers and journalists, training workshops aimed at non-experts including journalists and invitations for journalists to visit its headquarters (Townsend, 2011).

- *Straight Statistics* campaign (http://www.straightstatistics.org/) is established by journalists and statisticians to improve the understanding and use of statistics by government, politicians, companies, advertisers and the mass media. The web site states the aim is "*to detect and expose the distortion and misuse of statistical information, identify those responsible and to restore public confidence in statistics*".

- Other examples include the *Numbers Guy* blog which is based on the weekly Wall Street Journal Column and examines numbers in the news, business and politics (http://blogs.wsj.com/numbersguy/) and the Guardian Datablog (http://www.guardian.co.uk/news/datablog).

These lists are by no means complete. Our goal here is to highlight examples of successful projects aimed at moving towards the ultimate goal of statistical literacy in the population. Links to web sites giving a detailed description of these and many other initiatives related to the promotion of statistical literacy can be found in our collection of web resources presented in Section 4.2.

2.3 Statistics as a Profession in the UK and Other Countries

The current problem with teaching statistics and with the public awareness of statistics should be considered in the context of the state of statistics as a profession and of statistics training provision. While this paper is mainly focused on the UK, the relevant published articles, reports and reviews produced in different countries point out that the field of statistics faces the same challenges, including educational problems, in different countries across the world. In fact, in several developed countries there is a pronounced shortage of statisticians in science and industry and a decline in statistics teaching in universities. (See e.g. the report of the National Science Foundation on the US statistics profession, by Kettenring, Lindsay and Siegmund, 2003; the review 'Statistics at Australian Universities', 2005; sponsored by the Statistical Society of Australia Inc.; and the International Review of Mathematical Sciences (IRMS), 2010, in the UK.)

In the Australian experience, the desperate situation facing mathematics and statistics has been highlighted recently by two significant reviews into the mathematical sciences: Statistics at Australian Universities (2005) and Australian Academy of Science (2006). Australian Academy of Science (2006) alerts us to the fact that "*the number of mathematics and statistics students and lecturers at Australian universities is critically low*" and "*the nation's capacity to support research, research training and advanced education in mathematics and statistics is diminishing rapidly*". In a similar vein, the national review by the Statistics at Australian

Universities (2005) warns that there are real threats to the sustainability of the core academic discipline in the country. In particular, insufficient numbers of PhD students are being trained to meet the needs of academia and research-based industries. The existence of a general shortage of statistics graduates is a long-standing problem in Australia and Peter Hall (2004), former President of the Australian Mathematical Society, describes the state of statistics in Australian universities as in continued decline. Today, Australia has very few departments of statistics and there are very significant difficulties in filling vacant positions of professional statisticians.

In New Zealand, educators consider statistics as at a critical juncture and call for new approaches to teaching statistics to reach a new group of learners and facilitate statistical understanding in fundamentally new ways (Wild, Pfannkuch, Regan and Horton, 2011). The traditional mathematical approaches to statistics have resulted in inequitable educational outcomes (Wild and Pfannkuch, 1999). The new strategies to teaching statistics through encouraging investigative enquiry and conceptual understanding are reflected in the new statistics curriculum of the Ministry of Education (2007). The curriculum was developed over a number of years with consultation across a wide range of groups. In the new curriculum, the statistics profile has been increased, the learning area of Mathematics has been re-named 'Mathematics and Statistics' and its strand now includes statistical investigation, statistical literacy and probability. The new school curriculum implicitly supports new approaches to statistics and emphasises the changes needed in both the pedagogy and thinking behind statistics education and the urgent need for statistics education for critical citizenship. The national statistical office, Statistics New Zealand, has also contributed to these efforts by increasing its investment in both internal and external statistics training over the last few years. The need for intervention was identified by a lack of capability and recruitment and retention problems in the public sector (Forbes, 2008).

The position of academic statistics in the USA is consistent with that of the rest of the world. Lindsay, Kettenring, and Siegmund (2004) emphasise that the number of people with training in statistics is not growing fast enough to meet the high demands for statistical expertise in today's science, engineering and government laboratories and agencies. The authors of the report admit that although the statistics field has a huge potential, its realisation in the US is compromised because "resources are too limited, the pipeline of students is too small and the infrastructure supporting the field is too constrained". This is echoed by calls for educational improvements. The American Statistical Association (GAISE K-12 Report, 2007; GAISE College Report, 2010) and leading statistics educators (e.g., Cobb, 2007; Rossman, 2008) emphasise the need for reforms in the way statistics is conceived and taught.

In the UK, a number of reviews have examined and outlined the current and changing climate of university statistics teaching. The influential Roberts Review (2002) '*SET for success'* reported a shortage of the supply of science, technology, engineering and mathematics skills throughout the education system and contained a number of recommendations aimed at improving the attractiveness of research careers. More recently, the Smith and Staetsky (2007) report raised a number of worrying questions about the state of statistics in the UK and the possible consequences for university statistics departments. Serious concerns about the current state of mathematics and statistics research in the UK were also raised in the two international reviews of Mathematics (IRM, 2004) and Mathematical Sciences (IRMS, 2010) conducted by

the Engineering and Physical Sciences Research Council (EPSRC). These reviews are part of the series of international reviews commissioned and managed by EPSRC in collaboration with relevant learned societies in a range of subjects, with the aim of establishing an independent assessment of the quality of UK research compared with international standards.

In the first report, IRM (2004), undertaken on behalf of the EPSRC and the Council for the Mathematical Sciences, the international review panel looked at pure mathematics, applied mathematics and statistics across the country. The report gave separate consideration to the field of statistics reflecting the fact that the UK's international position in research at that time was considered seriously threatened by structural and personnel issues. Statistics was considered to be an area where the outlook was much more alarming than for pure and applied mathematics in terms of filling academic positions.

The second review, IRMS (2010) was carried out by a panel of 16 international experts. This review once again devoted a special section (Section 15 "Structural Issues Specific to Statistics") for discussion of the situation in the UK statistics research community and concluded that

"...the UK statistics research enterprise is in a fragile and weakened condition, despite all its areas of excellence and the welcome measures taken during the intervening years to strengthen it."

The major problems outlined in the review included the weakening and closures of small statistics departments where research strength in statistics has been diminished by retirements, job moves by prominent statisticians, a lack of PhD training, the diminution of statistics as a separately recognised field in the UK (in contrast to the situation in the US, where undergraduate statistics majors are increasing), the marginalised position of statistics in school curricula, and the underrepresentation of women.

Another recent initiative of the Economic and Social Research Council (ESRC) echoes the concern about qualified staff. ESRC is changing the way that it funds postgraduate training by introducing a new Postgraduate Training Framework. Instead of funding individual departments and courses, the ESRC has created a national network of 21 institutional or consortia level Doctoral Training Centres (DTCs). DTCs are aimed at promoting the development of more coherent university-wide core training programmes for postgraduate training in the social sciences including training pathways in statistics and quantitative skills. (See 'ESRC Postgraduate Training Framework' (2009), found at http://www.esrc.ac.uk/_images/Postgraduate_Training_and_Development_Guidelines_tcm8-2660.pdf.)

In a recent discussion on the future of the statistics profession in the *American Statistician*, leading figures in the academic research community agreed that it is an important time of rapid change in the subject of statistics and in the way that statistics is taught (see e.g. Brown and Kass, 2009; Meng, 2009; Hoerl and Snee, 2010).

Of course, issues outside the university sector also play a role in producing these outcomes in statistics at the tertiary level. They include a widely publicised shortfall in trained, skilled high

school mathematics and statistics teachers (see, e.g. Roberts Review, 2002; Statistics at Australian Universities 2005). Different educational bodies are actively calling for changes in statistics education in schools with a number of recommendations and guidelines produced for helping teachers to achieve a better understanding of statistics at school level (see e.g. Statistics at Australian Universities, 2005; Davies, Marriott, and Gibson, 2006; GAISE K-12 Report, 2007).

In summary, the discipline faces fundamental challenges in all areas of statistics teaching and training to reform the future of the profession (see e.g. Brown and Kass, 2009). While there has been a startling growth in the demand for statistical education, the supply of lecturers and teachers for the future is in jeopardy.

3. Strategies for Reform-Based Teaching of Statistics

In brief, the goals of statistics educational reforms are to change attitudes towards statistics, and to improve the teaching and learning of statistics. To achieve these goals, a large number of research studies have been conducted from various perspectives, which can be divided into three categories: (1) teaching and learning methods; (2) using technology in statistics education; and (3) the evaluation of the teaching and learning methods suggested by researchers. The aim of the next section is to provide an overview of the recommendations and strategies for teaching that have been suggested. The evaluation of pedagogic strategies is not considered in this review. The emphasis is rather on summarising the examples of good practice which have already been generally evaluated and approved by the statistics educational community. The theme of technology is particularly important for statistics education and is discussed in the second section.

3.1 Review of Teaching and Learning Strategies and Recommendations

Studies that have focused on revising traditional methods of teaching statistics, suggest changes which should be implemented to enable students to receive training which is both up-to-date and relevant to society's needs. The major directions of the statistics education reform movement involve (a) pedagogical reforms toward development of conceptual understanding and teaching to statistical thinking and reasoning; (b) changes in the content of statistics courses, especially introductory level courses; (c) improving the instructional techniques used in statistics courses; and (d) integration of technology and computer-based methods into teaching statistics as an important tool for effective delivery of teaching and essential part of effective pedagogy (see e.g. Cobb, 1992; Moore, 1997; Garfield, 1995; Garfield and Ben-Zvi, 2007). All these imply that traditional lecture-based teaching methods should be replaced or supplemented by new approaches which reframe the roles and identities of teachers and learners. To be more effective, teaching and learning activities should be designed and implemented to take pedagogical principles of learning into account. In order to determine whether innovative teaching methods are effective, a link to a theory or theories of learning can be the instructor’s most powerful tool in understanding and changing practice.

Cognitivism is currently one of the predominant perspectives within which human learning is described and explained (Atherton, 2011). Cognitive theory addresses how people understand

material and develop aptitude and capacity to learn through different learning styles. In the context of statistical education, Lovett and Greenhouse (2000) present five principles of learning derived from cognitive theory:

I. Students learn best what they practice and perform on their own.
II. Knowledge tends to be specific to the context in which it is learned.
III. Learning is more efficient when the students receive real-time feedback on errors.
IV. Learning involves integrating new knowledge with existing knowledge.
V. Learning becomes less efficient as the mental load students must carry increases.

Cognitivism is the basis of the educational approach known as constructivism, which emphasises the role of the learner in constructing his own view or model of the material. Much of the recent reform movement in education, especially in science and mathematics including statistics, has been based on cognitive constructivism. This theory explains the process of learning as actively constructing knowledge, which interacts with previous knowledge, beliefs, and intuitions. Constructivism is guided by four principles – learners construct their own meaning; new learning builds on prior knowledge; learning is enhanced by social interaction; and learning develops through "authentic" tasks (Cooperstein and Kocevar-Weidinger, 2004).

These ideas are not new. Over a decade ago, Garfield (1995) proposed ten general principles for learning statistics formulated in the context of constructivism theory and based on the underlying idea that learners create their own understanding of the material. In line with constructivist pedagogy, Garfield's learning statements encourage statistics teachers to build up an active learning environment in the classroom and to give greater attention to the attitudes and beliefs of the learner in the development of their knowledge of statistics. Recently Garfield and Ben-Zvi (2007) revisited the principles of how students learn statistics, and principles from Garfield (1995) have been regrouped in light of current research in the statistics education discipline.

An active learning environment is an important facet of the constructivist approach to instruction. Examples of active learning methods to teaching statistics include, but are not limited to, collaborative and cooperative learning, problem-based learning and problem solving, case studies, course projects, project-based learning, simulations, and the use of technology.

Collaborative and cooperative learning involves students working together in some way to aid their learning. Cooperative learning is defined by a set of processes which help people interact together in order to accomplish a specific goal or develop an end product which is usually content specific. It is more directive than a collaborative system of governance and closely controlled by the teacher. In collaborative learning, participants work together to solve a problem and often the teacher does not have a pre-set notion of the problem or solution that students will be researching. The cooperative learning approach is teacher-centred whereas collaborative learning is more student-centred.

Research into cooperative and collaborative learning in teaching statistics has demonstrated positive results and effectiveness on a range of outcomes which include: improved attitudes, positive growth in student achievement, improved relations among different ethnic groups,

and increased personal and social development (Garfield, 1993; Roseth, Garfield and Ben-Zvi, 2008). Roseth, Garfield and Ben-Zvi (2008) also point out that cooperative learning groups enhance critical thinking, conceptual understanding, and other higher order skills.

Another form of active learning is Enquiry-Based Learning (EBL). EBL can be described as learning that arises out of a structured process of enquiry within a supportive environment, and which is designed to promote collaborative and active engagement with problems and issues (Lancaster, 2011). EBL is an empowering, strongly student-centred approach to learning and teaching with benefits for subject learning (Deignan, 2009; Metz, 2008). The flexibility of the method allows for the development of a wide range of student abilities and skills in areas including initiative, critical judgment, openness, creativity and independence of mind (Kahn and O'Rourke, 2005).

EBL is an umbrella term covering different forms of learning driven by a process of enquiry, including the more widely known approach of Problem-Based Learning (PBL). PBL is a method that facilitates learning through problem solving activities. One of the main defining characteristics of PBL, which distinguishes it from some other forms of EBL, is that the problem is presented to the students first at the start of the learning process, before other curriculum inputs (Barrett, 2005). PBL was originally developed for use in the training of medical students. Among the most notable applications of PBL are the medical school programs at McMaster University (Canada), where PBL was pioneered in the late 1960's, and the Faculty of Health, Medicine, and Life sciences at Maastricht University (Netherlands), which embarked on the innovative pathway of PBL in the 1970's. The effectiveness of PBL within such domains as medical education and nursing is now well established (see e.g. the meta-review by Albanese and Mitchell, 1993). PBL has excited interest among educators around the world for several decades. It has spawned a number of variants and has been extended to other disciplines including statistics. Examples of the implementation of PBL in statistics courses indicate that students are more engaged with the subject, motivation and commitment are greatly improved and, in general, the approach is positively received by the students (Boyle, 1999; Marriott, Davies, and Gibson, 2009; Jaki and Autin, 2009).

The full range of pedagogical theories underlines the importance of utilising correct educational strategies, encouraging deep learning approaches, such as active learning and problem-based learning, and emphasising statistical thinking. Based on our literature review Table 2 provides a brief description of some reform-based techniques and examples of how they are used in practice. We do not suggest that this list is comprehensive but it demonstrates a variety of innovative instructional techniques that are being employed in a variety of successful statistics classes today. These methods tend to lead to improvements in students' interest in statistics, their learning outcomes, or both.

3.2 Technological Innovations

Technology is and will be a major part of our everyday life and it is increasingly being used as a teaching resource in many different forms. The dramatic increase in technology has led to a real impact on the statistics discipline in general and on the training of both professional

Table 2. Overview of Reform-Based Learning Strategies and Techniques

Suggested Strategy	**Examples of Use**
Shifting the focus of statistics curricula from mathematical calculations to tasks of a practical nature. (Chance, 1997; Allen et al., 2012)	• Students are given problems within different contexts so they exercise what they have learned in a variety of ways. • Consider real world examples and applications.
Developing problem solving skills. (Garfield, 1993; Garfield, 1995; Marriott, Davies & Gibson, 2009)	• Implement problem-based learning strategies giving students open-ended problems and taking the role of "facilitator" in the learning process. • Use of real life examples in project work.
Developing strategies to motivate students. (Garfield, 1993; Snell, 1996a; Watson,1997)	• Provide examples that have recently appeared in the media, government reports, news.
Developing statistical literacy and critical thinking skills. (Wallman, 1993; Gal, 2002; Gal, 2003; Schield, 2004)	• Include a statistical literacy component in the introductory statistics course. • Focus on everyday arguments that use statistics as evidence. • Use examples of incorrect analyses and examples of statistical illiteracy from the media.
Integrating new authentic assessment techniques that address students' ability to evaluate and utilize statistical knowledge, communicate and justify statistical results, and produce and interpret computer output. (Chance, 1997; Garfield & Gal, 1999; Garfield & Chance, 2000)	Incorporate non-traditional assessment techniques and innovative models which might include: • a computer laboratory component, • a term project with peer reviews and oral presentations, • a take-home component to the final exam, • minute papers (brief, sometimes anonymous, written remarks provided by students during the last few minutes of class), • student journals, • portfolios of student work (a collection of students' work, often gathered over an entire course), • concept maps (graphical representations of an individual's knowledge framework which demonstrate the concepts and the connections that relate them), • critiques of statistical ideas or issues in the news.
Integrating a scheme for assessment of statistical thinking and statistical literacy in to the curriculum. (Gal, 2002; Schield, 2004; Watson, 1997)	• Using media reports and newspapers articles to assess students' ability of interpretive statistical thinking.

Service teaching statistics in the context of the serviced discipline. (Verhoeven, 2006; Gordon, Petocz & Reid, 2007)	• Use of real data sets and subject related problems. • Team teaching.
Suggested Technique	**Examples of Use**
Collaborative and cooperative learning. (Garfield, 1993; Garfield, 1995; Roseth, Garfield & Ben-Zvi, 2008)	• Students work together to solve problems or discuss concepts, sharing ideas and understanding. • Collaborative group work with computers.
Active learning and introducing activities where students are able to construct knowledge. (Garfield, 1993; Garfield & Ben-Zvi, 2008)	• Students are engaged in data collection, reflection on and exploration of statistical concepts, and solving problems on their own. • Small-group cooperative learning (as one of the ways for teachers to incorporate active learning); • Students' engagement in active learning can be fostered by concept mapping. • Use different forms of technology promoting statistical thinking and reasoning, e.g. Personal Response Systems as an approach to employ active learning in the classroom
Target misconceptions through discussion and assessment. (Garfield, 1995; Chance, 1997)	• Instruction is designed so that students will be confronted to discuss their misconceptions. • Introduce interactive assignments with feedback.
Develop the skill of communicating statistics. (des Nicholls, 2001; Rumsey, 2002; Schield, 2004)	• Translate and present complex concepts into a format understandable to a wide audience. • Ask students to explain terminology and to interpret the statistical results in everyday words. • Using news and other media sources. • Simulations of real life experiences.
Use of technology and on-line resources. (Garfield, 1995; Ben-Zvi, 2000; des Nicholls, 2001; Mills, 2002)	• Presentation of new material with the use of statistical software. • Simulation programs which allow students to explore statistical concepts in discovery-world environments. • Using useful resources available online. • Use of podcasting, PRS facilities, video-lecturing.

statisticians and users of statistics in particular. The role of technology in statistics education was emphasised in the IRM report of 2004:

"The subjects of probability and statistics … have been revolutionized by technological changes that have resulted in a huge change in scale of the empirical data and the computational power now widely available."

The progress in computing technology has resulted in changes in the way in which students learn statistics and the way in which instructors teach statistics (Moore, Cobb, Garfield, and Meeker, 1995; Chance, Ben-Zvi, Garfield and Medina, 2007). Whereas students were once expected to solve problems by performing tedious hand calculations or to derive particular statistical formulas, now course goals refer to statistical literacy, students' ability to reason statistically about real-world problems and the development of active learning skills. Modern learning theories emphasise the importance of constructivism when integrating technologies in learning.

Technology has also expanded the range of graphical and visualisation techniques to provide powerful new ways to assist students in exploring and analysing data and thinking about statistical ideas, allowing them to focus on the interpretation of results and understanding concepts rather than on computational mechanics. Most importantly, graphics is a universal language which makes graphical exploration of data a very influential tool helping the better understanding of concepts in mathematics, statistics and science.

Recently, animation emerged as a new area of scientific visualisation. Animated visualisation is a powerful and compelling technique which has a huge potential (Rosling, 2007). Hans Rosling's GapMinder (Rosling, Rönnlund and Rosling, 2004) is one of the most well-known examples of successful animated visualisations. One of Rosling's talks available online can be found at http://www.ted.com/talks/hans_rosling_shows_the_best_stats_you_ve_ever_seen.html. Rosling uses his animation to make powerful points about both our preconceptions about public health problems and the differences between the developed and developing countries. The extremely fast-developing technology offers numerous technological tools for statistics education. Information technology facilitates statistical computing, graphing, and the way educational materials are delivered. Following the GAISE College Report's (2010) classification of technologies currently available, the types of technology used in teaching statistics and probability can be grouped into several categories: graphing calculators, statistical software packages, educational software, applets, spreadsheets, classroom response systems, web-based statistics related resources including data repositories, online texts, and data analysis routines. This list can be complemented by computer simulation methods, multimedia materials and such relatively new technologies as podcasting and computer-based testing.

We do not aim to give an exhaustive list of the technological resources available for teaching statistics; it is beyond the scope of this paper. A useful summary of the recent developments in the use of technology in teaching statistics can be found in Chance et al. (2007). Authors highlight some of the common technological tools that are currently in use in statistics education and give an overview of research on technology in statistics education. For more

insight see also proceedings of the special International Association for Statistical Education Roundtable which was convened to discuss the current state of research on the role of technology in statistics education (Garfield and Burrill (ed.), 1996). A detailed review of computer simulation methods classified by topic of statistics is given by Mills (2002). Another example of successful technology which might enhance good pedagogical practice in the classroom is the use of Personal Response Systems (PRS). The systems have a variety of names: Audience Response Systems, Student Response Systems, or just clicker systems. Banks (2006) presents recent research on the use of PRS in higher education and suggested directions for using this technology to improve student learning (see also Titman and Lancaster, 2011). Another important pedagogical tool for promoting understanding is applets. Applets have great value because they vividly show students certain concepts visually. Agresti and Franklin (2009) adopt a concept-driven approach in an undergraduate introductory statistics text which includes numerous activities and applets.

While technological developments provide numerous enhancements to the teaching of statistics, the development of the World Wide Web has produced an unprecedented global means for instructors to easily share their ideas on ways to improve statistics education. In the next section we outline the potential of the Internet, the medium which has enabled researchers and educators of statistics to share information in volumes that would have been logistically difficult and very expensive in the past.

4. Potential of Web-based Learning Environments

The Internet has made the world a smaller place. It has evolved into the main communication system for the academic world and proved to be an extremely efficient medium for teaching and learning. Access to the Internet has opened up new sources of information and new means of communication between students and teachers. It is widely recognised now that fast-developing Internet technologies have brought new possibilities and directions for teaching in general and for the teaching of statistics in particular. Snell (1996b) remarked that the Internet adds a new dimension to the teaching of statistics. Indeed, over the past 15 years we have witnessed a big increase in the use of the Internet as a resource for teaching. Interactive multimedia technology and e-learning have the potential to significantly alter practices at all educational levels (Garfield and Burrill, 1996; Rubin, 2007; Tamim, Bernard, Borokhovski, Abrami, and Schmid, 2011).

While there is a tremendous amount of information available on the World Wide Web for the teaching of statistics, it is essential that instructors and researchers take full advantage of the newest technological developments. However, there are very few studies where statistical issues and the Web have been discussed systematically. The aim of this section is to provide a systematic general overview of statistics on the Web that introduces and compares useful Web-sites, makes teachers and students aware of a multitude of online teaching tools and, hopefully, motivates them to explore more resources on their own.

4.1 Overview of Research on the Use of Web Resources in Statistics Education

The use of online learning environments (hypermedia) in education is expanding. Dillon and Gabbard (1998) reviewed the research literature on the Web as an educational technology. The authors examined the published findings from studies on a general type of information resources - 'hypermedia'. Although their analysis showed that the benefits gained from the use of hypermedia technology in learning scenarios appear to be very limited, they conclude that well-designed hypermedia offers the potential to enhance learning in a variety of ways.

In the subjects of mathematics and statistics, the flexibility of modern Web technology-based environments in providing different kinds of materials for different levels of students (novice, experts), and different learning paths is conceived as a strong benefit (Alajaaski, 2006). Many authors discuss the potential and characteristics of learning using a web environment. They point out that self-directed learning or student-centred learning is particularly important for e-learning, even if the e-learning resource supports innovative pedagogical tools. It is emphasised that the intervention of the teacher is required for effective e-learning (Symanzik and Vukasinovic, 2003; Schuyten and Thas, 2007).

As Web technologies evolve, social software such as Blog, Wiki, and social bookmarking are becoming increasingly popular. Accordingly, their use in the classroom has increased. In recent years, Wikipedia, a Wiki-based encyclopedia using collective intelligence, has increased in popularity. Also, use of Wiki has been increasing in statistics education. Ben-Zvi (2007) used Wiki to assist in collaborative learning. He argues that Wiki is useful for facilitating collaborative learning, it brings instructional change to improve student learning of statistics, and gives students and teachers more opportunities for communication, feedback, reflection, and revision. He presents several types of Wiki-based activities: collaborative writing, glossaries, discussion and review, statistical projects, self-reflective journals and assessment.

Today, many statistics courses have been taught making use of Web based statistical tools to supplement and/or enhance teaching and learning. Using Web resources in teaching statistics varies from occasional interactive exercises and in-class demonstrations to completely online courses. A popular approach is a combination of online teaching and traditional teaching referred to as a hybrid or blended course (Utts, Sommer, Acredolo, Maher, and Matthews, 2003). The goal of the blended learning approach is not to substitute the face-to-face interaction that naturally occurs in the traditional classroom but to use the technology in numerous ways to enhance and expand the classroom that supports student learning. Studies show similar student performance between the online/blended course and the traditionally taught course, with online and blended learning approaches being positively received by students (Utts et al., 2003; Tudor, 2006). Symanzik and Vukasinovic (2006) describe their experience of teaching a Web-enhanced face-to-face course that uses the commercial electronic textbook CyberStats. Their approach also fits into the term "blended learning" (or b-learning) incorporating both lectures and online materials. The summary of overall trends and themes in teaching statistics through online courses can be found in the paper by Mills and Raju (2011) which reports the results of an extensive review of the literature in several disciplines from the last decade.

Some researchers (Nolan and Temple Lang, 2007; Schuyten and Thas, 2007) argue that the development of pedagogical content and/or web resources can benefit from the same collaborative model as that upon which open-source software is built. Materials and experiences could then be shared by statisticians. This could enhance the development of even more e-learning objects and improve their maintenance.

Standards have proven crucial in the development of educational tools and media to ensure positive uses and although increasing activity in multimedia/web education components can be observed, we are far from developing standards in this important area. While research supports the use of web technology to facilitate and improve the learning of statistical concepts, there are cautions that statistics educators need a system to critically evaluate existing web sites and their education components (Ooms and Garfield, 2008). Despite the huge popularity of new hypermedia, obviously the new technologies should only be advocated when they provide added value.

Many statistics courses have been taught that make use of Web based statistical tools such as teaching software tools, electronic textbooks, and statistical software on the Web. However, while the use of technology for education and training by higher education is growing, statistics educators point out that there are certain barriers in implementation and integration of information technologies into educational activities. We list below some problems in incorporating web technology in the statistics classroom:

- It is difficult to grasp the amount and variety of the statistics-related material on the Web. It might be even more difficult to obtain information on where to find statistics-related sites and how to use the available material (Symanzik & Vukasinovic (2003)).
- As Strauss (2005) mentioned, teachers are not welcoming the rapid change in technology.
- Some authors emphasise the lack of a pedagogical framework for web-based education (see e.g. González, Jover, Cobo, and Muñoz, 2010).
- It takes time and thought to effectively incorporate new technologies (Chance et al., 2007).

With the intention of making a start in bridging the gap between web-based teaching resources and their adoption by statistics instructors, in the next section we provide a systematic overview of useful on-line resources.

4.2 Overview of Web Resources for Statistics Education

As Internet access in educational settings expands, educators' interest in using online educational resources has steadily increased (Ooms and Garfield, 2008). Using online resources for teaching statistical courses provides numerous advantages over more traditional teaching formats. The Internet has proved to be an extremely efficient information delivery method, bridging physical gaps and barriers between users around the world (Snell, 1996b). In addition, the Web is widely used to store and disseminate information. In this context the number of resources about statistics and self-learning materials on the Web has dramatically increased over the past few years and has helped transform the way statistics is taught

(Phillips, 2003). However, research by Hofer, Yu, and Pintrich (1998) indicates that most learners have difficulty in self-regulating their own learning and need more structure in the learning materials. The overview of useful Web resources presented in this section aims to make roads into structuring a large collection of possible tools and, hopefully, to make these resources more accessible for teachers of statistics.

Internet resources include collections of activities, data sets, web applets, text materials, assessment items and a wide range of websites which present rich and motivating teaching material. The goal of this section is to provide a flavour of the available online tools for teaching statistics, highlighting some of the more common examples of each type of tool. In the next section, we present an annotated list of some of the resources, which are *freely* available online, together with their strengths and weaknesses, audience level, content and interface design.

Due to the rapidly evolving nature of the Internet, new resources are appearing at a steady rate. In this overview we try to provide a current snapshot of the status of Web resources for teaching statistics and to direct readers to the various sorts of websites currently available via the Web to help support statistics instruction. We have grouped the resources into different categories based on their purpose. Although not listed repeatedly, many web sites contain information that can be classified into more than one category. Note also that many web sites are interlinked and provide access to the other sites included in our listing. The resources we have collected are organised into the following groups:

1. **On-line statistical course materials and lectures.** Advances in technology coupled with increasing student enrolment numbers have led universities to begin offering on-line classes. The growing number of distance learning and online classes has led to increasingly different types of statistical course materials available online, including video lectures. While these are often designed to support online or blended learning classes, the materials can also be used for independent learning and teaching.

2. **Learning repositories and teaching materials.** In recent years learning repositories located on the World Wide Web have become a popular and important part of statistics education. These materials often combine several different types of online resources including exploratory activities for use with students, supplementary methodological course materials with hands-on demonstrations, simulations and interactive graphical displays, and pedagogically rich data sets. Probably the most well-known are MERLOT and CAUSEweb (see description in Table 3). Both are user-centered, searchable collections of peer reviewed and selected higher education, online learning objects. These repositories contain thousands of learning materials in various formats which can be freely accessed and used for faculty, staff and students on the Web.

3. **Web-based data resources and repositories**. The Internet is a source of a vast and growing array of interesting data sets and provides instructors with a variety of options for finding data for realistic, engaging instruction and exercises. Many websites contain data which has been especially designed or selected for teaching certain statistics topics. From a long list, the *StatLib Datasets Archive* and *The Data and Story Library* (DASL) are examples of well-established sources of datasets and an excellent

place to start exploring data. While numerous data repositories exist, in Table 3 we list just a few of the sites where data is freely available for teachers and students to help show the application of statistics using real world data.

4. **Online statistics textbooks.** A number of individuals and groups have undertaken projects to develop statistics textbooks that can be accessed via the Web. Table 3 gives some examples of high quality freely available online statistics texts. Many statistics texts now have a website associated with them, and these often contain a rich source of additional material, datasets, and exercises.

5. **Statistical literacy.** Links to websites or statistical societies which relate to or promote statistical literacy. This category includes a wide range of sites which can be referred to for popular statistics topics which may be of interest to statistics educators: online magazines, blogs, journalists' websites, etc.

6. **History of statistics.** Learning from experience of our historical counterparts can provide valuable examples of applying statistical reasoning to practical situations of interest and developing methods of learning statistics (Lancaster, 2011). Information from these sites can be used to add interest to classes and provide information for student assignments.

7. **Electronic journals on statistics education.** The number of electronic journals is growing and they are an important source for instructors for hints and ideas on improving their own courses. Published papers describe approaches that may be of interest to statistics educators and contain references to statistical issues in the current news media which may be useful for case studies, student reports, and projects. Table 3 lists the most well-known free to access examples of electronic journals.

8. **Data visualisation.** Technology enables visualisation of statistical concepts and processes, demonstration of complex abstract ideas and provision of multiple examples to enhance learning (Chance, et al. 2007). This section provides examples of websites with interesting and popular data visualization tools. The list also contains links to good visualisation examples which demonstrate how visualisation can help users explore and understand data, and also communicate that understanding to others.

9. **Statistics Applets.** Probably, the most common way to use information technology to enhance teaching materials in mathematics and statistics has been to add statistics applet illustrations letting students experiment with mathematical statements. Some of these illustrations are very sophisticated and valuable new elements in instruction. The emergence of Java as a platform-independent web programming language has encouraged individuals to develop interactive demonstration software which can be accessed over the Web and used for the purpose of statistics education. While these tools are too numerous to list here, Table 3 gives examples of the sites with useful annotated statistical applets. CAUSEweb also gives a peer-reviewed annotated list of such tools.

10. **Miscellaneous links related to statistics.** In this category we include information on a number of sites containing miscellaneous collections of statistics related links. This section provides good examples of useful and extensive collections of statistical links that have been established and maintained by many individuals who are interested in statistics and regularly update their links. These links redirect to sites with different types of materials. Some of the sites are designed by and for statistics educators. Others are related to media sources. Often these web sites are related to popular statistics and science in general. In our view the materials from this category of the Web resources can be used in the class to encourage and motivate students in their learning of statistics.

As we have already mentioned, there is some overlap in the capabilities of the tools across these categories. Since new web-based tools are continually being developed for higher education, the list presented does not attempt to be exhaustive.

4.3 Annotated List of Statistics Related Web Links

In this section we present the collection of Web links that may be useful for teaching and learning statistics. Table 3 contains the list of these reviewed and summarised Web resources. The sites are intended primarily for practising and training teachers, who are or will be teaching students at college or university. They provide accessible information on a range of teaching and learning issues. The criteria for inclusion into the collection were different. Primarily, web sites listed here were those that have been mentioned in talks at leading statistics education conferences like ICOTS, RSS and others; those described in papers and other web sites as examples of good practice; those recommended by colleagues teaching statistics; and those that we have used in our own teaching.

Although the volume of on-line material may seem daunting, and the process of searching for worthwhile information can be frustrating, the rewards, both for instructors and our students, can be quite substantial. The sites described in Table 3 are extensive, and though others may eventually be added, these will likely persist, because most of them have already existed for a number of years. The URLs listed in Table 3 were active when this paper was written. We apologise for URLs that are no longer available.

For each Web resource the table provides information about the site including reviewed strengths and found weaknesses. The sites are classified by audience: General Public, Higher Education, Undergraduate and Postgraduate as subsections of higher education, and Introductory which includes first courses in statistics for both undergraduate and postgraduate students. The ‘Content / Subject’ column includes a number of categories related to teaching and learning, for example, pedagogy, assessment, subject specific service teaching, and e-learning.

Interface design is assessed using principles of intuitive navigation: Can the user move quickly through the site without having to stop to think or read too much? Does the site provide good links and annotated links so users know ahead of time where they are going? Do the graphics enrich content and add to it in a logical fashion, not merely decoratively?

We follow this model of intuitive website navigation to assess usability and structure of the site by considering its framework, the organisation of content, the prioritisation of information, and the method in which the user moves through the site. Sites which are consistent, intuitive, transparent and allow the user to form a mental model of the information provided are considered as sites with good structure and navigation. It should be noted that interface design does not reflect the quality of site content. Also, we would like to point out that our scale for measuring website usability is subjective and in many respects indicates authors' opinion.

The links are supported by references to corresponding printed articles when available.

5. Conclusion

Statistics has been and will continue to be one of the most widely taught topics at university level. Over the last two decades, the foundation for statistics education studies has substantially strengthened into the independent research area that it is today. There has been a tremendous increase in research studies focusing on the teaching and learning of statistics and probability. While statistics education has turned into a research area of increasing interest, implementing new instructional techniques and achieving an appropriate balance between theory and application is a challenging task. In this article we conducted a review of the research literature on teaching and learning of applied statistics at the university level. We have attempted to outline the identified problems and possible solutions in teaching statistics and to review extensive resources currently available to instructors in statistics on the Web.

It is clear that statistics teaching has benefited from the development of the technological resources that are available. We overviewed the role of technology in teaching and learning of statistics, in particular Internet based resources, and examined and typified web-based materials about statistics and teaching statistics. The purpose of the summary presented in the paper is to direct readers to the most useful websites that are currently available via the World Wide Web to help support statistics instruction more effectively. Web-based learning can be seen as an alternative and complimentary tool in statistics education that has the potential to radically influence what and how we teach. We believe that efforts in reforming statistical education may be broadened by using topical, interesting, substantive problems coming from the actual practice of statistics that are placed on the web in various repositories.

The use of the Internet in education is increasing and becoming more refined. In this context we would like to emphasise the need to better understand the process of finding, evaluating, and organising electronic statistical resources, and for giving referenced credit to those who developed them. The question of evaluating Web sites becomes more and more important and is not being adequately addressed. Given the vast, dynamic, and ever expanding nature of the Internet and the wide ranging quality of information, it is essential that tools for evaluating the information found on the Internet are developed.

Over the years a number of innovative teaching methods have evolved in response to changes in technology and statistics education reform. It is hoped that the availability of innovative

educational technologies makes thinking about complex domains – such as statistics – more accessible to learners. There is a large body of pedagogical research and it is important for statistics teachers to stay informed about new findings. We have summarised current resources available in statistics education and have made some suggestions for effective use of statistics educational research findings in the classroom. This literature review is not exhaustive. It does not discuss, for example, statistical software packages, spreadsheets or graphing calculators.

In conclusion, this review shows that statistics education is a unique rapidly evolving discipline and computer-based and Web technologies are an important and integral part of statistics today. We hope that this paper will contribute to the understanding of the current state of statistics education providing a bridge between research findings in statistics education and teaching practice which will help teachers understand and implement Internet technology in a variety of innovative ways.

Table 3. Annotated List of Useful Online Resources for Teaching Statistics

Strengths	Weaknesses	Audience / Level*	Content / Subject	Instructional Resources						Interface design	Interaction with the site	Host / Institution / Authors	Related printed references
				Data	E-textbooks	Tutorials	Video tutorials	Using multi-media	Interactive hands-on activities (inc Java Applets)				
1. On-line statistical course materials and lectures													
http://surfstat.anu.edu.au/surfstat-home/surfstat.html **SurfStat.*australia*.** An online statistics course with a collection of Java applets to work with different statistical procedures.													
Contains collections of useful links to general statistics resources. A number of exercises with solutions are provided.	Limited list of statistics topics. Some links do not exist.	I	e-learning		X				X	Average	Email	Keith Dear (project leader) with team, University of Newcastle (Australia)	
http://videolectures.net/Top/Mathematics/Statistics/ **VideoLectures.NET.** Video lectures on mathematics and statistics topics, free and open access educational video lectures repository. The lectures are given by distinguished scholars and scientists at important and prominent events.													

Extensive portal with high quality didactic content. The lectures are accompanied by available related information, documents, links or slides. All lectures are selected and classified through an editorial process.		GP	Video lectures given at events such as conferences, summer schools, workshops.				X	X		Excellent	Email, blog, "ticket system" (to submit request and upload data)	Host: Jozef Stefan Institute (Ljubljana, Slovenia)	
2. Learning repositories and teaching materials													
http://ore.gen.umn.edu/artist/ **ARTIST** (Assessment Resource Tools for Improving Statistical Thinking). The ARTIST project web site provides a variety of assessment resources for teaching first courses in Statistics. The authors state that the goal is to help teachers assess statistical literacy, statistical reasoning and statistical thinking in first courses in statistics.													
The ARTIST Assessment Builder is a searchable database of more than 1000 test questions for introductory statistics concepts. Allows searching for assessment items according to statistical topic and type of learning outcome.	Registration is required to use the database and to access the ARTIST online tests. The page shows it was last modified a few years ago: September 2006.	I	Assessment							Below Average	Email, feedback form	Robert delMas, University of Minnesota (USA); Ann Ooms, Kingston College (UK); Joan Garfield, University of Minnesota (USA); Beth Chance, California Polytechnic State University (USA)	The paper by delMas,Ooms, Garfield, & Chance (2006) describes the ARTIST project.
http://www.causeweb.org/ **CAUSEweb.** Website of "Consortium for the Advancement of Undergraduate Statistics Education" (CAUSE), an online repository of statistics education resources. Part of this site is a catalogued collection of statistical resources, such as lecture examples, datasets, and applets.													

Large and continually growing collection of online teaching and learning materials (around 2000 annotated resources in 2010). "Teacher – friendly": contains lesson plans, teaching materials for particular pedagogical methods, annotated statistics education research. Peer - reviewed.	Difficulties with searching: existing search engine is not always helpful in quickly finding the required materials	UG	Teaching & Learning, Pedagogy, Assessment	X	X	X	X	X	X	Very Good	Email	CAUSEweb is a multi - institutional organisation arising from an initiative of the American Statistical Association	See Everson & Gundlach (2010) for a brief description of CAUSEweb and its online resources. Other useful reference is Green, McDaniel & Rowell (2005).
http://www.dartmouth.edu/~chance/ **Chance.** The link contains materials designed to help teach a Chance course, an entirely Internet based course on quantitative literacy. The aim of a Chance course is to make students more informed and critical readers of current news items that use probability and statistics, as reported in daily newspapers, journals and magazines.													
The Chance Database includes materials and links to related Internet resources useful for teaching case study courses like a Chance course and that can be used for teaching a more standard introductory probability or statistics course.	The level is suited more to High School and College students.	I	Probability & Statistics	X	X		X	X		Average	Email	The Chance project was developed by Laurie Snell at Dartmouth College (USA) with the Chance team which includes: Peter Doyle, Joan Garfield, Tom Moore, Bill Peterson, and Ngambal Shah.	Snell (1996a)
http://www.statcan.gc.ca/estat/licence-eng.htm **E-STAT.** An interactive learning tool for students and teachers containing Statistics Canada's Census of Population and socioeconomic data. Statistics Canada's information is translated into learning resources that are relevant to the actual curriculum taught.													
Provides visualisation tools, lesson plans and handouts by topic.	The resource is primarily developed for school level. The materials are free online but available only to educational institutions (licence agreement).	I, UG	Teaching & Learning	X		X				Very Good	Email, phone	Statistics Canada	Townsend (2008); Townsend (2011)

http://www.webster.edu/teachstats/ **Hulsizer & Woolf Book.** Additional material to the book of Hulsizer & Woolf (2008) maintained by the authors. Provides ideas for teaching statistics on different topics with corresponding references and other useful teaching statistics material not included in the book: information on texts, assignments, demonstrations, means of assessment, and technologies relevant to the teaching of statistics.													
Provides well-researched advice and guidance on teaching statistics that reflects current recommendations from the statistics education reform movement.	The site is not independent and may be used only as supplementary material to the printed book.	HE	Subject specific service teaching (Psychology)							Average	No	M. Hulsizer and L. Woolf, Webster University (St. Louis, Missouri, USA)	Hulsizer & Woolf (2008)
http://www.merlot.org/merlot/index.htm **MERLOT** (Multimedia Educational Resource for Learning and Online Teaching). One of the most well-known learning object repositories that contains thousands of learning materials in various formats. The MERLOT website includes Statistics Portal which is a joint venture with CAUSE and some links back to the CAUSEweb site. In addition, there are links that will allow users to search through the MERLOT statistics and probability learning materials.													
User-centred, searchable collection of online learning objects catalogued by registered members. Wide range of online teaching materials on a variety of subjects in one portal. Peer - reviewed.	With thousands of different objects in one place, sometimes it is difficult to search/find a particular resource or material	HE	Teaching & Learning, Pedagogy, Assessment	X	X	X	X	X	X	Average	Email	Created by the California State University Center for Distributed Learning (USA) in 1997	Everson & Gundlach (2010)
http://stat.cst.cmich.edu/statact/ **Real-Time Online Activities for Statistics.** An online database that hosts the data collected from in-class hands-on activities conducted by students. The purpose of this project is to implement activity-based hands-on activities in a corporative learning environment using technology.													
Promotes activity-based learning and cooperative learning. The web site provides a detailed tutorial on how to use the real-time database (how to download, save and read data).	Limited number of activities implemented.	I	Teaching datasets, Assessment	X					X	Below Average	Email, feedback form	Carl Lee (project director) with team, Central Michigan University (USA).	Lee & Famoye (2006)
http://onlinestatbook.com/rvls.html **Rice Virtual Lab in Statistics** (RVLS). Has four components: (1) an introductory hypertext online statistics book (see also description below in "Online statistics books" section), (2) collection of Java applets that demonstrate various statistical concepts, (3) "Case Studies" with examples of real data with analyses and interpretation, (4) "Analysis Lab" with data analysis programs for some basic statistical tools.													

Award winning courseware with a substantial introductory-level statistics book extended by search capabilities, a glossary, analysis tools, and instructional demos. The simulations and demonstrations have links to the explanatory material in e-book HyperStat Online from RVLS. Promotes active learning and hands-on student-centred learning.		I, UG	Teaching & Learning, e-learning		X	X		X	X	Average	Feedback form	The site has been developed by David Lane, Rice University (USA), with other contributors.	The detailed description of RVLS is given in a paper by Lane & Scott (2000).
http://www.socr.ucla.edu/SOCR.html **SOCR** (Statistics Online Computational Resource). A free, interactive and Internet-accessible resource for data exploration, modelling, analysis and interpretation. SOCR tools and resources include a repository of interactive applets, computational and graphing tools, instructional and course materials.													
SOCR framework comprises of a hierarchy of portable online interactive aids. One of the largest collections of Java applets, it is useful for interactive learning, motivating, modernising and improving the teaching format. Promotes active learning and hands-on student-centred learning.	Intensive use of animation and Java applets at SOCR web site may cause problems for some users to access and interact with the SOCR resource. As the portal becomes more extensive it becomes more difficult to navigate.	UG	Probability & Statistics		X		X		X	Average	Email	Ivo D. Dinov is the project leader, University of California, Los Angeles (Los Angeles, USA).	Dinov (2006), one of the resource developers, gives more details about SOCR. See Dinov & Christou (2009) for outline of the most recent version of the repository.
http://www.statsci.org/teaching.html **StatSci.org.** Part of the extensive StatSci.org website. Contains statistical teaching initiatives and resources from around the world. Extensive collection of statistics related links, focused on teaching resources.													

Extensive index directory of statistical science resources on the web. The main concept of the site is that the directory will not attempt to include a primary listing for every useful site but will link to key sites from which all other resources can be reached quickly. Where reliable key sites do not exist original resources were created.	The site needs updating. Some links presented in this portal do not exist.	HE	Teaching & Learning	X	X		X		X	Average	Email	Gordon Smyth, Walter and Eliza Hall Institute of Medical Research (Australia).	
http://www.stats.gla.ac.uk/steps/ **STEPS** (STatistical Education through Problem Solving). The project website contains problem-based teaching and learning materials for statistics. The material consists of 38 teaching modules and is based around specific problems arising in Biology, Business, Geography and Psychology. It also provides a glossary of statistical terms and software which is freely available to educational institutions and its use is encouraged.													
Encourages problem-based learning. The STEPS teaching modules are intended to be used as lab material and to support existing coursework. Each module is supplied with appropriate documentation.	The STEPS project came to an end at the close of 1995 and the website was last updated in January 2004. The STEPS material was designed for use under Windows 3.1/3.11 and may not work under more recent versions of Windows.	I	Subject specific service teaching (Biology, Business, Geography, Psychology), Teaching & Learning			X			X	Very Good	Email	The STEPS consortium included nine departments in seven UK universities: Universities of Glasgow (lead site), Lancaster, Leeds, Reading, Sheffield, Nottingham Trent University and UMIST.	
3. Web-based data resources and repositories													
http://www.censusatschool.org.uk/ **CensusAtSchool.** An international project collecting and disseminating real data for use in data-handling, information communications technology and across the curriculum for teaching and learning. Databases contain nearly 2.2 million data responses from learners in the UK and overseas collected over ten years. All of the resources on the website are free to download and use, unless otherwise stated. The data collected are from and about school-aged learners but can also be used in tertiary education.													

The project encourages the purposeful use of real data and promotes the teaching and learning of statistical thinking skills in the classroom. The website is well documented with useful examples.	The material is mainly intended for High School and College students.	I, UG	Teaching & Learning	X		X				Very Good	Feedback form, phone	The Royal Statistical Society Centre for Statistical Education, University of Plymouth (UK)	Davies (2011)
http://lib.stat.cmu.edu/DASL/ **DASL** (Data and Story Library). An online library of data files and stories that illustrate the use of basic statistical methods.													
Stories are classified according to statistical methods and major topics of interest. The material can be searched by method, topic or data subject. The data comes from a wide variety of topics so teachers can find real world examples that their students will find interesting. Provides datasets that have been cleaned up and formatted to use in teaching statistics.		UG	Archive	X						Average	Yes, including submitting new story or data	DASL Development Team includes Matthew Hutcheson, Mike Meyer, Cara Olson, Paul Velleman, John Walker.	
http://www.esds.ac.uk/ **Economic and Social Data Service** (ESDS). The UK's national data service providing access to and support for an extensive range of key economic and social data, both quantitative and qualitative, spanning many disciplines and themes.													

The ESDS Data Catalogue contains over 5,000 datasets. ESDS also provides teaching datasets which are typically subsets of the larger UK government surveys. 35 teaching datasets are currently available.	All data are free but users of ESDS must be registered with the service (registration is free) to access the data, using federated access management (shibboleth) authentication. To download any data you must register with ESDS, agree to an End User Licence (EUL) and provide details of your intended use.	GP	Archive	X						Very Good	Email	University of Essex, University of Manchester (UK)	
http://www.amstat.org/publications/jse/jse_data_archive.htm **JSE Data Archive.** Journal of Statistics Education archive of datasets for teaching. Data are in various formats including .dat, .txt, and .xls, with text documentation files included.													
A large collection of datasets, many associated with articles in the JSE.		HE	Pedagogy	X						Average	Email	JSE	Lock & Arnold (1993)
http://www.stars.ac.uk/ **STARS**. 'Creation of Statistical Resources from Real Datasets' project. The project uses real datasets and scenarios to help develop teaching and learning resources for staff and students. The statistics packages used are Excel, MINITAB, SPSS and, to a minor extent, SAS.													
Contains a number of scenarios with related datasets which can be used for teaching. Worksheets (with solutions) are available on many introductory topics, from graphs to multiple regression.	Some links are not working.	I	Teaching & Learning, Subject specific service teaching (Business, Health, Psychology)	X		X				Average	No		
http://www.umass.edu/statdata/statdata/index.html **Statistical Datasets.** This electronic service provides access to a collection of datasets suitable for teaching statistics. The collection of links is organised by statistical topic.													

The datasets have been organised by statistical technique to make it easier to find a dataset appropriate for one's pedagogical needs.	The data are mostly US related. Limited number of statistical topics.	HE	Teaching & Learning	X						Below Average	No	University of Massachusetts (Amherst, USA)	
www.statsdatasets.com **Statistics Data Sets for Teaching**. The Lancaster University datasets project. Website provides a resource for the sharing of datasets and dataset links useful for teaching statistics, and the background and nature of the datasets.													
Repository allows datasets to be searched by topic and disciplinary area. The website is being developed with the aim to provide both datasets and links to datasets, teaching materials, references to publications and code.	It is an ongoing project. The site is under development.	HE	Teaching & Learning	X						Average	Email	Department of Mathematics and Statistics, Lancaster University (UK)	Paper by Hoti, Francis & Lancaster (2010) gives more details about the project and website.
http://lib.stat.cmu.edu/index.php **StatLib**. A system for distributing statistical software, datasets, and information by electronic mail and WWW.													
Extensive searchable collection of data, statistical software, news from the statistics community, and other information related to statistics which started in 1989. There are several sites around the world which serve as full or partial mirrors to StatLib, automatically synchronised, to provide a reliable and network efficient service.		GP	Archive	X						Average	Yes, including submitting new software or data (registration required)	Hosted and maintained by the Department of Statistics at Carnegie Mellon University (USA).	Paper by Kooperberg (1997) describes an early version of the system.
4. Online statistics textbooks													
http://cast.massey.ac.nz/collection_public.html **CAST** (Computer-Assisted Statistics Teaching). Contains a collection of electronic textbooks that teach statistical methods. Three e-books cover material in introductory statistics, other e-books teach more advanced topics.													

All textbooks take a data-focused approach to the subject and use minimal mathematics. Introductory statistics books use data sets and scenarios from different application areas. The three introductory books come with e-book of exercises. The books can also be downloaded for quicker access from your hard drive.		UG	e-learning		X				X	Average	Email	Doug Stirling, Massey University (New Zealand)	
http://www.itl.nist.gov/div898/handbook/index.htm **Engineering Statistics Handbook.** The goal of this online text is to help scientists and engineers to incorporate statistical methods as efficiently as possible. It discusses many statistical concepts in an Engineering framework. There is good coverage of designed experiments, time series, statistical process control, as well as basic techniques.													
Although this text is Engineering focused, the information contained in this site is also useful for other applications. The book includes tools, aids and a searchable database.	Engineering focused only	UG	Subject specific service teaching (Engineering), e-learning		X					Average	Email	National Institute of Standards and Technology NIST / SEMATECH (USA)	
http://www.davidmlane.com/hyperstat/index.html **HyperStat**. Online statistics textbook with links to other statistics resources on the web. Online book is structured as tutorial with 18 lessons covering basic topics.													
A very well-designed and well-constructed online textbook covering first-year non-calculus based statistics with very helpful interactive support.	The web site is a bit overloaded with additional links and sometimes advertisements.	I, UG	e-learning		X	X			X	Below Average	Email	Maintained by David Lane, Rice University (USA).	Briefly described in Lane & Scott (2000).
http://www2.chass.ncsu.edu/garson/pa765/statnote.htm **StatNotes.** The website provides a thorough description of a variety of topics in statistics. Articles typically contain an overview, an explanation of key concepts and terms, assumptions, frequently asked questions and a bibliography. Textbook for an advanced course in research methodology with a focus on statistical modelling of public policy and management.													

The online text contains articles on a range of statistical topics. The articles on the site describe each method, discuss the underlying assumptions of the method, and some implementations of the methods, reviewing a variety of software packages.	Aimed at using mainly SPSS as the course software.	HE	Subject specific service teaching (Public administration)		X					Average	Email	David Garson, North Carolina State University (USA)	
http://www.statsoft.com/textbook/ **StatSoft E-book.** StatSoft has freely provided this Electronic Statistics Textbook as a public service. From the website description: "The Electronic Textbook begins with an overview of the relevant elementary concepts and continues with a more in depth exploration of specific areas of statistics, organized by 'modules', representing classes of analytic techniques. A glossary of statistical terms and a list of references for further study are included."													
Complete on-line statistics textbook with clear descriptions of many statistical areas. The only Internet Resource about Statistics recommended by Encyclopedia Britannica.		HE	Teaching & Learning		X					Excellent	Email	Developed by StatSoft	Hill & Lewicki (2007) (printed version)
http://www.stat.berkeley.edu/users/stark/SticiGui/index.htm **SticiGuionline**. Philip Stark, Professor of Statistics at the University of California, Berkeley, has written an on-line text "Statistical Tools for Internet and Classroom Instruction with a Graphical User Interface" which he has used in teaching Berkeley's Introductory Statistics course.													
This resource provides an online introductory statistics textbook together with Java applets, exam reviews, a statistics glossary, video lectures and other tools. Well maintained, last modified June 2011.		I	Subject specific service teaching (Business, Communications, Economics, Psychology, Social Science)		X		X	X	X	Average	No	Philip Stark, University of California (Berkeley, USA)	
http://www.psychstat.missouristate.edu/sbk00.htm **Stockburger IS Book.** Online book "Introductory Statistics: Concepts, Models, and Applications" by David W. Stockburger. Includes also David Stockburger's list of all types of statistical resources.													

In-depth coverage of introductory statistics. A searchable Web text with extensive use of web technology.		UG	Subject specific service teaching (Psychology, Behavioural Sciences), e-learning		X				X	Very Good	Email	David W. Stockburger, Missouri State University (USA)	
http://www.psychstat.missouristate.edu/multibook/mlt00.htm **Stockburger MVS Book.** David W. Stockburger's book, "Multivariate Statistics: Concepts, Models, and Applications". A continuation of the Introductory Statistics text by the same author with an emphasis on mathematical concepts. Covers hypothesis testing in regression, principal components, cluster analysis, discriminant function analysis, multiple regression, dummy coding, and ANOVA.													
A searchable Web text with extensive use of web technology and interactive graphics to illustrate multivariate concepts.	Some material may be too advanced for UG level.	UG, PG	Subject specific service teaching (Psychology), e-learning		X				X	Very Good	Email	David W. Stockburger, Missouri State University (USA)	
5. Statistical literacy													
http://www.badscience.net/ **Bad Science.** Ben Goldacre's website devoted to satirical criticism of scientific inaccuracy, health scares, pseudoscience and quackery, it focuses especially on examples from the mass media, consumer product marketing, problems with the pharmaceutical industry and its relationship to medical journals, and complementary and alternative medicine in Britain. It is complemented by the book 'Bad Science' which criticises media reporting on health and science issues and contains extended and revised versions of many of Goldacre's Guardian columns.													
The weekly Bad Science column written for the Guardian since 2003 is archived on this site along with blogposts, columns for the British Medical Journal, and other writing. The articles can be browsed by category.	The examples need to be adapted for teaching.	GP	Statistical Literacy							Average	Email, blog	Ben Goldacre	Goldacre (2008)
www.getstats.org.uk **Getstats.** The Royal Statistical Society launched a Statistical Literacy Campaign on 20 October 2010, building the website www.getstats.org.uk into a portal for statistical literacy for the public and others. The project aims to contribute to an ambitious cultural change in the use of data and statistics.													

The site includes information about useful links to sites about statistics. The project is collecting teaching and learning resources for all audiences. Includes a collection of videos on popular mathematics and statistics topics.	This is an ongoing project. The site is under development.	GP	Statistical Literacy					X		Average	Feedback form, email, phone	Royal Statistical Society (UK)	
http://www.bbc.co.uk/news/magazine-14917871 **Go Figure.** A regular column by Michael Blastland about the everyday use of statistics. (The link on the left is related to the latest column as at December 2011.)													
A weekly BBC series. Provides up to date information on misleading uses of statistics which can be used as teaching examples.	The examples need to be adapted for teaching.	GP	Statistical Literacy					X		Very Good	Comments blog	Michael Blastland, BBC News (UK)	
http://www.stat.auckland.ac.nz/~iase/islp/home **International Statistical Literacy Project** (ISLP). The project of the International Statistical Institute with the main objective to improve statistical literacy. The mission of the project is to support, create and participate in statistical literacy activities and promotion around the world.													
Provides an online repository of international resources and news about statistical literacy. The project is collecting international statistical literacy resources for all audiences and in several languages.	Not related to teaching directly.	GP	Statistical Literacy, Pedagogy, Teaching & Learning							Average	Email	International Statistical Institute	Sanchez et al. (2011)
http://www.senseaboutscience.org.uk/ **Sense About Science**. An independent UK based charitable organisation promoting good science and evidence for the public and responding to the misrepresentation of science including statistics.													
Provides up to date information on misleading uses of statistics which can be used as teaching examples.	The examples need to be adapted for teaching.	GP	Statistical Literacy							Very Good	Email	Sense About Science (London, UK)	
http://andrewgelman.com/ **Statistical Modeling, Causal Inference, and Social Science.** Andrew Gelman's statistics blog with entries organised by categories.													

An excellent blog covering different statistical topics.	The examples need to be adapted for teaching.	HE	Teaching & Learning							Average	Blog	Andrew Gelman, Professor in the Departments of Statistics and Political Science at Columbia University (USA). He maintains the blog together with Bob Carpenter, Aleks Jakulin and Phillip Price.	
http://www.statlit.org/ **StatLit.** Website devoted to statistical literacy with the primary goal to present statistical literacy as an interdisciplinary activity.													
Well-structured web site. Includes a useful and extensive collection of links related to statistical literacy: http://www.statlit.org/Links.htm.	Not related to teaching directly.	GP	Statistical Literacy, Pedagogy							Below Average	No	StatLit website is independent of any organisation.	
http://www.stats.org/index.htm **STATS.** Another site which helps people to think about the numbers behind the news. Looks at major issues and news stories from a quantitative and scientific perspective. Initially it was designed as a resource for science writers. Founded in 1994.													
This site provides resources for journalists and policy makers on the use and abuse of science and statistics in the media. The materials can be used for teaching statistics to provide up to date insight into the real life use of statistics.	The examples need to be adapted for teaching.	GP	Statistical Literacy							Very Good	Feedback form, blog	George Mason University (USA)	
http://understandinguncertainty.org/ **Understanding Uncertainty.** David Spiegelhalter's project page. The project "Understanding Uncertainty" tries to make sense of chance, risk, luck, uncertainty and probability. Includes collection of animations.													

Website is an educational resource featuring the use of probability and statistics in everyday life, and makes extensive use of animations to help "tell the story" of the data. List of animations is well documented: each animation is provided with the description, the author and licensing information and links to the original articles. Extensive collection of web links.	Not related to teaching directly. Animations are mainly illustrative for the project articles. Materials need to be adapted for teaching.	GP	Teaching & Learning, Data visualisation	X			X	X	X	Average	Feedback form	David Spiegelhalter, Winton Professor of the Public Understanding of Risk, University of Cambridge (UK)	
6. History of statistics													
http://www.york.ac.uk/depts/maths/histstat/welcome.htm **History of Statistics.** Miscellaneous materials for teaching the history of statistics.													
Large collection of links to documents with information about the history of statistics and statisticians. Of particular interest is their "Life and Works of Statisticians".		HE	Teaching & Learning							Average	Email	This website is maintained by Peter Lee, Department of Mathematics, University of York (UK).	
http://www.anselm.edu/homepage/jpitocch/biostatstime.html **History of Statistics Timeline.** Brief timeline of contributions to statistics.													
Material could serve as a helpful aid in the teaching of statistics.	One page website.	HE	Teaching & Learning							Below Average	No	Jay Pitocchelli, Biology Faculty, Saint Anselm College (USA).	
7. Electronic journals on statistics education													
http://www.stat.auckland.ac.nz/~iase/publications.php **ICOTS Proceedings.** ICOTS stands for the International Conference on the Teaching of Statistics. The ICOTS conferences, held by IASE every 4 years, are the most important events on the international statistics education calendar. The last such conference, ICOTS 8, was held in Ljubljana, Slovenia in July 2010. "Publications of the IASE" page gives access to the papers from past ICOTS.													

The ICOTS papers cover a wide range of statistical education topics and give statistics educators and professionals around the world the opportunity to exchange information, ideas and experiences, to present recent innovations and research in the field of statistics education, and to expand their range of collaborators.	Some ICOTS papers are not peer-reviewed	HE	Pedagogy, Conference proceedings					X		Average	Feedback form	IASE	
http://www.jstatsoft.org/ **Journal of Statistical Software**. Publishes articles, book reviews, code snippets, and software reviews on the subject of statistical software and algorithms. Established in 1996.													
The contents are freely available on-line. For both articles and code snippets the source code is published along with the paper.		HE	Statistical software							Average	Email	Published by the American Statistical Association	
http://www.amstat.org/publications/jse/ **Journal of Statistics Education** (JSE). Publishes refereed articles, datasets, reviews, and tips related to all aspects of teaching statistics at all levels of education with an emphasis on postsecondary stage . JSE has been available electronically since its founding in 1993.													
Free electronic journal with pedagogical content.		HE	Pedagogy	X						Average	Email	Published by the American Statistical Association	
http://www.mathstore.ac.uk/?q=node/58 **MSOR Connections.** The quarterly newsletter of the MSOR Network. It aims to highlight news, activities and research on the learning and teaching of Mathematics, Statistics and Operational Research within Higher Education. The journal aims to promote, encourage, enhance and disseminate research, good practice and innovation in all aspects of the student learning experience within Mathematics, Statistics and Operational Research wherever these may be taught in Higher Education.													

The journal carries articles about teaching and learning developments, the use of computers, reviews of courseware, reports of conferences and workshops, information on new developments and releases of standard packages. Available internationally via the Network website and distributed free of charge to academics in UK higher education institutions.	For those outside the UK Higher Education sector a paid subscription scheme exists.	HE	Pedagogy, Teaching & Learning							Average	Email, phone	The MSOR Network, University of Birmingham (UK)	
http://plus.maths.org/content/ **Plus Magazine.** Free online magazine popularising mathematics. It publishes articles from the top mathematicians and science writers on various maths-related topics including statistics.													
Plus provides feature articles, which describe applications of maths to real-world problems, games, and puzzles, reviews of popular maths books and events, and a news section. Useful resource for maths school students and teachers.	The examples need to be adapted for teaching.	GP	Mathematics & Statistics							Very Good	Email, blog	University of Cambridge (UK)	
http://www.stat.auckland.ac.nz/~iase/publications.php?show=serj **Statistics Education Research Journal** (SERJ). A peer-reviewed electronic journal published twice a year. SERJ aims to advance research-based knowledge that can help to improve the teaching, learning, and understanding of statistics or probability at all educational levels.													
Free electronic journal with pedagogical content.		HE	Pedagogy							Average	Email	International Association for Statistical Education (IASE) and the International Statistical Institute (ISI)	
8. Data visualisation													

www.improving-visualisation.org.uk **Dataviz.** "Improving data visualisation for the public sector" project. The site supports public sector researchers to improve the way that they visualise data, by providing good practice examples and case studies. Examples presented on the site have been taken from published material available on the web.													
Extensive collection of different kinds of examples of visualisation. The site provides practical and step-by-step guides on how to visualise data and links to more detailed resources.	Materials are not adapted directly for teaching.	GP	Data visualisation					X		Average	Email	The project was commissioned by the Department of Communities and Local Government and carried out by Oxford Consultants for Social Inclusion (UK)	
http://www.datavis.ca/gallery/index.php **Gallery of Data Visualization**. Displays some examples of the best and worst of statistical graphics, to inform current practice, and provide some pointers to both historical and current work. Includes collection of data visualisation techniques and software links.													
Interesting collection of data visualisation images. The pages are organised as a list of images with detailed description and links to original sources.	Materials are not adapted directly for teaching.	GP	Data visualisation					X		Average	Email	Michael Friendly, Professor of Psychology, York University (Toronto, Canada)	
http://www.gapminder.org/ **Gapminder.** Hans Rosling's "Gapminder" is a non-profit foundation founded in 2005. The aim of the project is to develop tools for interactive visualisation of large databases on websites, with the objective to turn existing statistics into meaningful knowledge by displaying them as easily understandable moving graphics. Trendalyzer software used for producing animation was acquired by Google in 2007. Google has made a 2008 version freely available as Google Motion Chart.													
The free software enables inter-active animation of developmental statistics within enjoyable and understandable graphical interfaces. The site features excellent teaching and educational examples and resources including handouts, lessons plans, interactive presentations, and teacher guides.		GP	Animated graphics	X		X	X	X		Excellent	Feedback form	Hans Rosling, Professor of International Health at Sweden's Karolinska Institute.	Rosling, Rönnlund & Rosling (2004); Rosling (2007); Rosling & Johansson (2009).

http://datavis.ca/milestones/ **Milestones Project**. Milestones in the history of thematic cartography, statistical graphics, and data visualisation. Graphic overview of the events in the history of data visualisation and an illustrated chronology of innovations.													
Interesting and useful multi-media resource, containing descriptions of events and developments, illustrative images, and links to related sources (web and in print) or more detailed commentaries. Also provides list of many other useful collections of historical information.	Materials are not adapted directly for teaching.	GP	Data visualisation					X		Very Good	No	Michael Friendly, York University (Toronto, Canada) & Daniel Denis, University of Montana (USA)	Friendly (2007)
http://www.stats.gla.ac.uk/~adrian/rpanel/ **Rpanel**. The R package which has been designed to allow teachers to construct animations in as simple a manner as possible, as well as to provide existing tools for the use of animations in the teaching and learning of statistics. The package is aimed at those who know R but are not familiar with the technicalities of the various gui construction systems which are available.													
Particular emphasis on tools for the teaching of statistics (but not exclusively so). At the link an extensive description of the package can be found, together with a collection of examples.	Requires knowledge of the R language.	HE	Teaching & Learning					X	X	Below Average	Email	Adrian Bowman, Department of Statistics, University of Glasgow (UK)	Bowman, Crawford, Alexander & Bowman (2007); Bowman (2010)
9. Statistics Applets													
http://old.stat.duke.edu/sites/java.html **Duke Statistical Applets.** A collection of interesting Java applets demonstrating principles of probability and statistics.													
Collection of links to Java applet sites.	Some links are not working	I, UG	Probability & Statistics, Teaching & Learning						X	Below Average	Email	Department of Statistical Science, Duke University (USA)	
http://www.rossmanchance.com/applets/ **Rossman / Chance Applet Collection**. The applet collection was developed to help students in understanding abstract concepts associated with repeated random processes.													

Extensive applet collection. Chance and Rossman illustrate how simulation can be a powerful tool in helping students learn statistics, particularly the ideas of long-run patterns and randomness, in a concrete, interactive environment.		I	Teaching & Learning						X	Below Average	Email	Allan Rossman, Beth Chance and a team of programmers, Department of Statistics, California Polytechnic State University (USA)	Chance & Rossman (2006)
http://sapphire.indstate.edu/~stat-attic/index.php **STAT-ATTIC** (STATistics Applets for Teaching Topics in Introductory Courses). The web based database that contains links to and descriptions of over 600 applets that can be used for teaching introductory statistics topics.													
The site makes available a collection of over 600 applets on wide range of topics commonly covered in introductory statistics courses. Information on each applet includes source, url and a brief description. The database is searchable.		I, UG	Teaching & Learning						X	Very Good	Email	Concetta DePaolo, Scott College of Business at Indiana State University (USA)	DePaolo (2010)
10. Miscellaneous links related to statistics													
http://www.utstat.utoronto.ca/vukov/TeachingStats.htm **Teaching Statistics, eh?** Collection of miscellaneous interesting links on teaching statistics which include educational applets, examples for case studies, and many other things.													
Extensive collection of links useful for teaching (some are listed in this table).		HE	Teaching & Learning	X	X			X	X	Below Average	Email	Augustin Vukov, University of Toronto (Canada)	
http://psych.hanover.edu/APS/teaching.html#statistics **APS Teaching Resources.** Collection of teaching statistics resources links from the American Psychological Society.													
Extensive collection of links useful for teaching statistics to Psychology students or for an emphasis on Psychology.		HE	Subject specific service teaching (Psychology)	X	X				X	Below Average	Email	American Psychological Society. Maintained by John H. Krantz	

http://www.stat.auckland.ac.nz/~iase/links/start **IASE Links Page.** The International Association for Statistical Education (IASE) collection of links. A gateway to statistics education resources around the world.													
Extensive collection of categorised links related to statistics education.		HE	Teaching & Learning	X					X	Average	Feedback form	IASE	
http://www.statsci.org/index.html **StatSci.org**. The author describes the site as "a window to statistical science and bioinformatics on the web", with special attention to Australia. StatSci.org consists of two parts: Resources and Directory. The resources are a set of services and the directory is an index of statistical science resources on the web.													
Extensive collection of categorised links related to statistics.	Some links presented in this portal do not exist.	HE	Teaching & Learning	X	X		X	X	X	Average	Email	Gordon Smyth, Walter and Eliza Hall Institute of Medical Research (Australia)	

*I = Introductory; UG = Undergraduate; PG = Postgraduate; HE = Higher education; GP = General public

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