Performance Assessments in Computer Science - An example of student perceptions

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Abstract

Computer science studies in universities have changed from broad study programs to more specialized study programs in the last decade. This change stems from a growing field, need from the industry, and from students. In some areas of applied computer science such as for example information security and networking, professional certifications play an important role as a way of assessing the practical knowledge, but also to meet the needs from the industry. A study by Morris et al. (2012) reveals that companies value some certifications more than a university degree in the area of networking, highlighting the issue of assessing practical knowledge. Since many of the certifications offered are too vendor dependent (Ray and McCoy, 2000) or lack educational rigor (Jovanovic et al., 2006) it is not always feasible to include them in higher education for practical assessment.

Another way of assessing how students perform in practical tasks is to use performance assessments. Using performance assessments as a complement or replacement of written examinations or lab reports is also a way of decreasing plagiarism among students.

This work presents a case study performed to investigate the perceptions of performance assessments among educators and students. The case study object selected is the Network and system administration study program given at the University of Skövde, Sweden, which has a long tradition of using performance assessments as an integrated part in the courses. Data collection has been performed using on-line questionnaires, document studies and interviews.

The results from the case study clearly indicate that the students perceive the performance assessments as something useful that measures their practical skills in a good way. It also shows that most of the students do not perceive the performance assessments as something more stressful than handing in a written lab report. We also present how a progression of performance assessment can be built into courses, and how the students perceive the progression.

Keywords

Performance assessment, examinations, progression, computer science studies.

Introduction and background

In the last decade, studies in computer science have transformed away from the broad computer science study program given at most universities, and today there are more than 300 computer science study programs to choose from only in Sweden[1]. Students strive for specialization since it increases their career possibilities, and this strive is met by the universities offering more and more specialized study programs. The specialization is also wished for by companies looking to hire students without having to invest too much time or money in training the employee in the initial employment period. The specialization has led to niched study programs such as for example game developer, web developer, enterprise system developer, interaction designer, and network and system administrator. Many of the specialized study programs are created to fit a specific job role, making it clearer for the student applying to the program, but also to employers looking to hire. There is not only a demand for theoretical specialization, but also for getting practical knowledge as a part of the university studies, that is also requested by the potential employers (Guzmán, 2011).

One way of assessing the practical knowledge in the IT field is through professional certifications that often assesses both practical and theoretical knowledge. In the IT field, Microsoft and Cisco dominates the vendor-specific certification market (McGill and Dixon, 2007), and they are also the most requested certifications by employers (Morris et al., 2012). In the field of network and systems administration, a university degree is important, but certifications are at least as important. For example, according to Morris et al. (2012) who analyzed 1,199 job advertisements for network engineers found that 26,1% requested a degree in computer science, and 30,9% requested a Cisco Certified Network Professional certificate. Certificate knowledge can be viewed in terms of a standardized course given at many universities with a very similar outcome regardless of where it has been taken. There are a number of benefits using certifications as an integrated part of higher education. From an employer perspective, Ray and McCoy (2000) mentions greater knowledge and increased productivity, a certain level of expertise and skill, improved support quality, reduced training costs and higher morale and commitment as benefits of employing students that have undertaken certification. From an educational perspective, the certification examination provides an additional tool for evaluating course and program content (Ray and McCoy, 2000), in attracting students (Brookshire, 2000), and it provides additional and generalizable measures of student competencies (McGill and Dixon, 2007). There is however a number of risks associated with IT certification. Since many of the certifications offered are vendor dependent, there is an absence of unbiased neutral groups for determining course contents, creating exams and authorizing examiners (Ray and McCoy, 2000). Jovanovic et al. (2006) describes the lack of educational rigor, too focused material,

[1] http://studera.nu

training-oriented rather than education oriented, and that it is too market and popularity driven.

We see that it is important from both a student, and employer perspective to give the students practical knowledge as a part of their university studies. However, the introduction of too many certifications might impact the quality of courses, and thereby the study program. One example is a network security course given as a part of the Network and Systems Administration study program (NSA) at the University of Skövde. Cisco has developed a CCNA Security course that is a continuation of the CCNA courses with the aim of learning how to secure Cisco networks. The course is in large extent Cisco-dependent, and parts of the course material are too basic, it is very vendor oriented and hard to generalize from. Furthermore, some important aspects of security, such as security in virtualization and cloud computing are missing, a belief shared by for example (Maj et al., 2010). In the light of this, a decision to develop a network security course that were not based on the CCNA Security material were taken, even if it might have been more attractive for both students and employers to give the CCNA Security course. In this course, and in the field, practical knowledge is very important, and labs and examinations need to reflect this.

Traditionally, many courses in computer science have a varying level of practice embedded in some way. An example could be a basic programming course where programming paradigms are presented theoretically, and labs complement the lectures. The practical part are assessed by a lab report, where the source code to solutions of questions posted in the lab instructions, complemented by a lab report are presented for examination. Despite the use of practical assignments computer science educators expresses concern for their students' lack of programming skills and studies often confirm their concern (McCracken et al., 2001, Lister et al., 2004). The kind of practical assignment described above is also prone to plagiarism (McCracken et al., 2001, Daly and Waldron, 2004).

One way of assessing how students perform in practical tasks is to use performance assessments. Performance assessments *"can measure students' cognitive thinking and reasoning skills and their ability to apply knowledge to solve realistic, meaningful problems"* (Lane, 2010, p.3). They "*emulate the context or conditions in which the intended knowledge or skills are actually applied*" (American Educational Research Association, 1999). There are other similar terms used for performance assessments, such as "performance tests," "performance assessment," or "authentic assessment" as pointed out by Lane (2010) and Sackett (1998), and in related fields "work samples" or "assessment center exercises" as mentioned by Lievens and Patterson (2011). Furthermore, Daly and Waldron (2004) gives an example of using "lab exams" which also appears to be a performance assessment.

Students consuming or producing information electronically experience greater level of tiredness and increased feelings of stress than when working on paper according to Wästlund et al. (2005). If the com-

puterized tests are used instead of a paper-and-pencil examination, the results might be that the students even feel less stress (Peterson and Reider, 2002). In the field of Computer Science, the alternative to a performance assessment is normally not a written examination but rather some kind of extended written report.

From this we draw the conclusion that there are broad issues concerning performance assessment, how it is implemented in a study program, and how the students perceive them. In this work we present a case study performed on the Network and Systems Administration study program given at the University of Skövde, where we present an approach with performance-based assessments with a clear progression and how the students perceive the performance assessments. The aim is to investigate the perception of performance assessments among educators and students. More specifically, three interrelated research questions have been specified:

- Do the students perceive the performance assessment as more stressful than examination with a written lab report?
- Do the students perceive the performance assessment as a positive aspect to highlight when applying for jobs?
- How do the students experience the progression of performance assessment between courses?

The authors of this article teaches courses and administrate the study program which implies full insight in course development, students progression in learning and the work on assessment as well. However, teachers share challenges in didactics that are necessary to raise in scientific debates.

Method and case study context

The method selected for this work is a case study as described by Walsham (1993). Case studies can take many shapes and be constructed with different aims. This case study is positioning as an interpretative case with the aim of gaining understanding as described by Braa and Vidgen (1999).
The case study object selected is the Network and systems administration study program given at the University of Skövde. The program started in 2004 and was among the first in the Nordics to educate network- and system administrators. The study program includes certifications from Cisco (mandatory), and Microsoft (voluntary[2]), but also performance assessment in a number of courses where no certifications are available or if certification is considered unfitting.

The data collection has been performed using documents describing the courses in which performance assessment are used, such as course plans and examination criteria, questionnaires and through group discussions. The questionnaires have been used to get a quantitative input on the students' perceptions of performance assessment. The questionnaires were designed to target three categories of students in three study programs. All of the students have participated in at least one course employing performance assessment. For all of the students this was their first course taken in

[2] There is a fee associated with the Microsoft certifications (contrary to the Cisco academic certification), so the courses prepare the students for certification.

their respective study programs. The student groups selected were (1) first year students in the NSA study program, (2) first year students in the web development and computer science study programs, and (3) second and third year students of the NSA program. With this setup we target primarily (a) one group of students exposed to several performance assessments, but also other types of examinations such as written examinations and lab reports. Secondly, we target one group (b) with limited performance assessment experience but with more experience of written examinations and examinations of lab reports. In the third group (c) we target students with more experience of performance assessment, but also other types of examinations. The third group also helps to answer whether or not the intended progression of the performance assessments is perceived. Data collection was performed in May-June of 2013, when the students had at least studied for almost one full year.

Case study

In this chapter, we will present the lab setup, and how the performance assessments are implemented in three selected courses given on the NSA study program. The selection of courses was made because there is a formal progression between them, both in terms of content, but also in terms of performance assessment progression. The progression of per-formance assessments will be outlined by detailing three courses, Computer Fundamentals, Windows-administration I, and Windows-administration II.

The lab used in the NSA study program is configured so that each work station is set up with two computers. The two computers are both equipped with hard drive carriers and the students are given their own hard drives for the course. The two computers have different hardware, where the more potent one is the server, and the other one is the client. The computers are isolated in their own IP subnets for optimum flexibility in different lab scenarios.

The trend in network and system administration labs is moving toward more and more virtualization[3] (Stackpole et al., 2008, Stewart et al., 2009, Wang et al., 2010). The students use virtualization techniques in a number of their labs to enable them to have multiple computer environments installed simultaneously. We mainly use the decentralized technique described by Li (2010) but provide the computer to install the virtual machine on and do not relay on the students' personal computers. We can and do use disk cloning[4] techniques for students in some courses where the installation of an operating system is not deemed as an integral part of the practical assignment.

The lab is equipped with VPN[5] (virtual private network) functionality, enabling the students to connect to their computers remotely.

[3] Virtualization in this context refers to the creation and usage of a virtual machine that acts like a real computer with an operating system. This is possible due to a separation of the system itself and the underlying hardware that is shared with other virtual machines.

[4] One copy of all the content of a hard drive is duplicated from one disk to another, to save time and effort in re-installation of a system.

[5] Enables a computer to send and receive (encrypted) data across a public networks such as Internet as if it were directly connected to the private network.

Computer Fundamentals is the first course given in NSA and two other study programs. The course normally has over 130 students, which mean that efficient assessment is of interest in this course. It is a 7.5 ECTS course where the lab part constitutes 4.5 ECTS and addresses these course objectives:

- describe the fundamental parts of operating systems and their different implementations
- install and configure computers

The lab is divided into two parts, each ending in a performance assessment. The first part involves installing two different Linux operating systems, one with a text based user interface and one with a graphical user interface. The student will then continue to set up necessary network configurations, add users and configure file system permissions and partitions, mainly in the text based system. The lab also introduces basic scripting. The students need to present their solutions to a supervisor as a prerequisite to the performance assessment.

The performance assessment is performed on the student's own hard drive. The time allowed is 2.5 hours and no conversations are allowed during the test. The students have full access to the Internet and other written resources. The test consists of three tasks, where one is considerably harder and gives extra credits toward a higher grade if passed. The two basic tasks test the skills that have been trained during the lab, often including adding users, adding a new shared directory with correctly set permissions, doing additional partitions, and/or doing an additional backup script. The higher grade task also tests skills trained during the practical lab but forces the students to combine them in other ways and check for details on the Internet to be able to successfully complete the task.

In the second part of the lab, the students install a Windows Server operating system on one of their hard drives and install virtualizing software on top of the Linux operating system on the other computer to be able to set up three different Windows client computers. The student will then continue on with, in many ways, the same sort of tasks as earlier but in a new environment. The students need to present their solutions to a supervisor as a prerequisite to the performance assessment.

The performance assessment for the second part of the lab follows the same pattern as the one for the first part. In this course no additional work from the students are needed from them. The completion of the labs, examined by the presentation, in combination with their two performance assessments will be the base of their grade for the lab part of the course.

Windows-administration I is a succeeding course of Computer fundamentals, given in the second semester of the first year. The course is a 7,5 ECTS of which 6 ECTS are for the practical assignment. It focuses on the need for centralization of system administration and backup and recovery. The practical part of the course addresses the following course objectives:

- independently install and perform basic configuration of servers and client computers

- create and realise backup and recovery plans for computer systems and data
- use tools for centralized administration of servers, clients and network resources
- describe and explain the theoretical foundations and central concepts within the area

In the practical lab the students will use their two assigned computers to set up a system consisting of two subnets and multiple servers and clients in respective subnet using virtualization. The students practice synchronization and replications issues between different physical sites (realized by the different subnets), central distribution of policies and software to clients, file sharing and centralized location of home directories, backup issues and strategies, and recovery of backed up data. This is a major practical assignment and it is divided into chapters (rather than parts) that need to be completed in sequence. Each chapter ends with a number of questions that the students need to be able to answer when presenting the lab. The students need to have presented their entire solution to a supervisor as a prerequisite to the performance assessment.

The performance assessment is performed on the student's own hard drives. The time allowed is 2.5 hours and no conversations are allowed during the test. The students have full access to the Internet and other written resources including their own documentation for their system. The test consists of three tasks, where one is considerably harder and gives extra credits toward a higher grade if passed. The two basic tasks test the skills that have been trained during the lab, often including running a small program that will add information to their system. The students will then have to perform a backup of files and be able to restore. Furthermore, identity and account management is tested as well as centralized administration.

Windows-administration II is a succeeding course of Windows-administration I, given in the second semester of the second year. It is meant to measure the student's ability to use their knowledge in multiple disciplines by having the students design and set up a complete computer system. The course is 4,5 ECTS and to enable them to set up a whole system, they are divided into groups of 5-6 students and need to collaborate and divide labor for the task to be feasible. The course objectives are:

- collaborate in groups to identify, implement, and document technical solutions based on a requirement specification
- describe and discuss the challenges in migrating data between different computer systems
- practically apply technical solutions that ensures high availability in computer systems
- reflect and discuss over the deficiencies and flaws in the proposed solutions from both a technical perspective and user perspective

The lab instructions give the students a lot of freedom to design their own system as long as it fulfills certain requirements regarding availability and functionality. Requirements can include efficient deploy-

ment of new clients, email and restoring of email-accounts, calendar, shared file storage, centralized user account management and the ability to restore all information even in the event of a complete physical destruction of one of the system sites. The students within the group are required to keep each other updated about their part of the solution and the overall understanding of the computer system is assessed in the individual presentation of the lab. Each individual will be asked to explain at minimum one aspect of the computer system that they have not personally been involved in.
The performance assessment is performed on the students' own hard drives. The time frame is around 3 hours, but since this is a test of a complex system there are circumstances that sometimes allow the students to ask for additional time. The students have full access to the Internet and other written resources including their own documentation for their system and the performance assessment is taken as a group test. It is a test to ensure that their plans for the system's availability work. The test involves turning off one of their hard drives, and wait for their monitoring system to tell them that an error has occurred. They then have to return their system to equivalent functionality and information availability as before the simulated hard drive failure.

In this course the students in addition to complete the lab and passing the practical test also need to document their system in a system documentation wiki and submit a report which reflects over their solution in regard to at least functionality, maintainability and security.

Results

The results presented in this chapter are divided into two categories, the results from the interviews with the educators and the results from the student survey.

Educators' experience

The interviews reveal that the experience of the educators that uses performance assessments in the NSA study program is positive and their opinion is that they measure the practical skills of the students well. The assessments seem to catch those students that may have gotten a little too much help during the lab, either from supervisors or other students, and not really absorbed any of the skills. This relieves some of the concern about the risk of helping students too much during supervised lab sessions, since there is an independent test of their skills in the end of the course. The possibility of plagiarism is also almost impossible in practical exams, and there is no greater need to cheat since they normally possess the possibility to use any available resource they like on the Internet. The educators point out that it is important to understand what skills are measured by the assessments and what knowledge is better examined in other ways.
In similar way as Daly and Waldron (2004) describe that their lab exams assess the student's programming ability, the educators of the NSA study program state that the performance assessments in the program assess the students skills at administering increasing complex systems, starting from a single computer in the first performance assessment in Computer Fundamentals to a system ranging over, at least, ten different servers, routers and multiple clients in Windows-administration II.

In regard to disparities between academic and practical skills, the educator seem to be united in their experience that it is the same students that excel at the performance assessments that excel at their theoretical academic work. This perception corresponds well with results presented by Buchanan (2006).

Students' experience

The students of the NSA study program are assessed and examined by performance assessments in multiple courses throughout their study program. In the questionnaire, distributed as an on-line survey, the students got to answer questions about how they felt about performance assessments. 44 students participated in the study that was conducted at the end of the school year (June of 2013).

The first questions asked whether the students' feel that performance assessments measure their practical skills, and if the students perceive it as a good way of measuring practical knowledge. There was very little difference between the three groups in this question. The large majority of the participating students perceive the performance assessments as a good way of measuring their practical knowledge. An even larger majority think it is a good thing to be examined by performance assessments. Figure 1 displays the results of these questions.

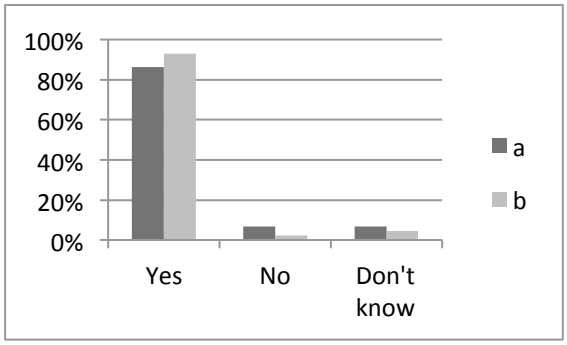

Figure 1. Students' response to questions regarding the desirability of performance assessments
a) Does performance assessments measure your practical skills?
b) Do you think it's good to be examined by performance assessments?

The next question investigated if the students perceive performance assessments as more stressful than submitting a written lab report. Figure 2 displays the combined view of all students participating in the survey, and about two thirds found performance assessments are less stressful.

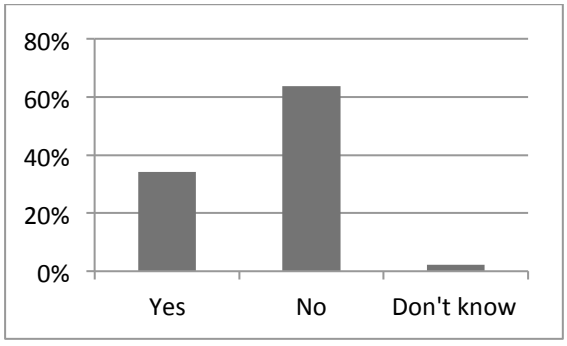

Figure 2. Students' response to:
Do you perceive performance assessments as more stressful than submission of a written lab report?

Figure 3 displays the answers per group, and there is a clear difference between the NSA students (group 1 and 3), and the non-NSA students (group 2). Almost half of the non-NSA students perceive performance assessments as more stressful than submitting a lab report.

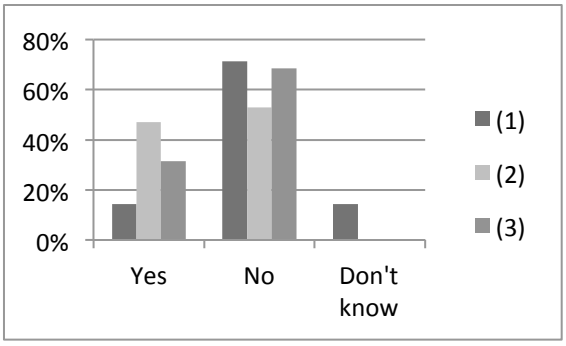

Figure 3. Students' response to:
Do you perceive performance assessments as more stressful than submission of a written lab report?
Divided by group 1, 2 and 3

The next question focuses on the student's perception of the believed usefulness of performance assessments when applying for jobs. This question was only asked to the NSA students since it is more important in their field. The results, as displayed in Figure 4, clearly indicate that the students perceive it as a positive thing when applying for jobs. It should be noted that some of the students had already started applying for jobs since the survey were performed just days before they had there last scheduled activity.

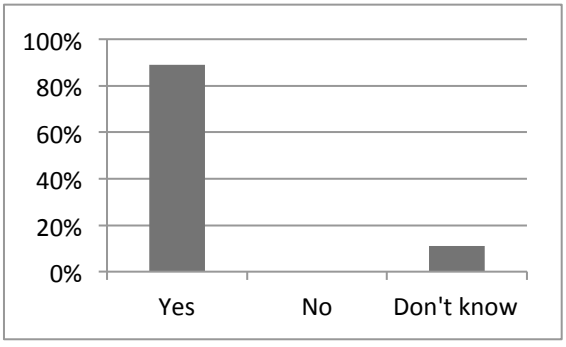

Figure 4. Students' response to: Do you think that the performance assessments in the NSA program is a positive aspect to point out when you apply for jobs?

The last question investigates if the students perceive that there is a clear progression in the performance assessments in the NSA study program. The question has only been asked to the second and third year NSA students, since they are the only group that has experienced the progression. A broad majority of the students feel that there is a progression in the performance assessments as Figure 5 indicates.

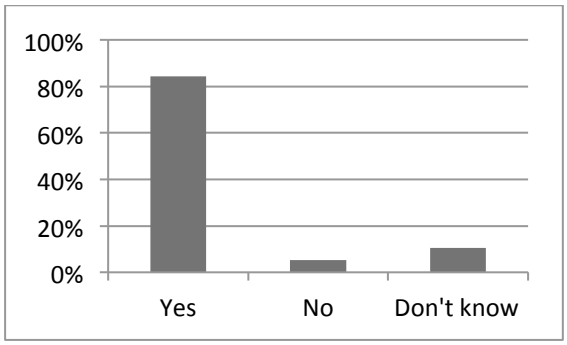

Figure 5. Students' response to: Do you feel that there has been a progression in the performance assessments in the program?

All students that participated in the survey had the chance to give a free-text comment. Of the 44 participants, 17 (39%) chose to leave a comment. The comments have been categorized into pros and cons.

The pros contained the most answers and one of the commenters wrote "I think all courses with a practical part should have performance assessment", and another "many companies wish for practical knowledge when applying for jobs… add even more performance assessments". The pros category also brings up an important aspect of working in the industry, where best practice is a rule of thumb. Among the answers were comments like "best practice need to be prioritized" and "a bad solution that might work but most likely will cause problems along the line should not be ok, best practice need to be considered". Some of the positive aspects from the students were related to the fact that they have to write less written reports, and views in-

cluded that performance assessments "proves in a better way the student have learned the course goals than repetitive "how-to" reports based on manuals and Google" and "the only real good argument [educators] have for examining lab reports is that it gives training for the FYP". Among the positive aspects, one individual commented that "performance assessment in the first course served as a soft start of the studies", an aspect of performance assessments previously unknown among the educators.

Among the cons we found individuals explaining that lab presentations and lab reports are a better way to examine and that performance assessments are too stressful. Furthermore, some raised notion about practicalities that can be improved, for instance regarding the preparations of the labs before a performance assessment. One of the commenters highlighted for instance a faulty network interface card in one of the computers in one of the performance assessments.

Conclusions

A single case study can provide important learning and insights (Siggelkow, 2007), but the authors acknowledge inherent limitations concerning generalization of results.

That both educators and students in the NSA study program in general were positive towards performance assessments were suspected prior to the study, and the study confirmed this belief. The most surprising results of the study are in regard to the experience of the stressfulness of taking performance assessments, which also is the main focus of the study. Of those less experienced in performance assessments (non-NSA students, group 2) about half consider them to be more stressful than submitting a written lab report. Of those that have performed multiple performance assessments, two thirds consider them less stressful than submitting a lab report. It also differs between the first year and the second and third year students. Among the second and third year students, one third thinks the performance tests are more stressful than submitting a lab report, while the first year students are more divided between more stressful and "don't know". This might be because of the progression and difficulty of the performance assessments. They are intended to get harder, and the higher stress from higher grades may reflect this fact. Another explanation could be that the students may have become more comfortable in writing lab reports. To be able to answer that question, a more in-depth study needs to be carried out.

An interesting comment coming from the free-text comments is the experience that a performance assessment is seen as a "soft start". This is not an aspect that the educators of the NSA program have considered earlier. Some of the problems with performance assessments are also mentioned in the free-text comments, for example with equipment that sometimes fail during a test.

References

American Educational Research Association, American Psychological Association, National Council on Measurement in Education, 1999. *Standards for educational and psychological testing,* Washington, DC,

American Educational Research Association.
Braa, K. & Vidgen, R. 1999. Interpretation, intervention, and reduction in the organizational laboratory: a framework for in-context information system research. *Accounting, Management and Information Technologies,* 9**,** 25-47.
Brookshire, R. G. 2000. Information technology certification: Is this your mission? *Information Technology, Learning, and Performance Journal,* 18**,** 1-2.
Daly, C. & Waldron, J. 2004. Assessing the assessment of programming ability. *SIGCSE Bull.,* 36**,** 210-213.
Guzmán, R. 2011. *Unga konsulter möter hårdare krav* [Online]. CSjobb: International Data Group. Available: http://www.idg.se/2.1085/1.363765/unga-konsulter-moter-hardare-krav [In Swedish] [Accessed 2014-02-14].
Jovanovic, R., Bentley, J., Stein, A. & Nikakis, C. 2006. Implementing Industry Certification in an IS curriculum: An Australian Experience. *Information Systems Education Journal,* 4**,** 3-8.
Lane, S. 2010. *Performance assessment: The state of the art,* Stanford, CA, Stanford University.
Li, P. 2010. Centralized and decentralized lab approaches based on different virtualization models. *J. Comput. Small Coll.,* 26**,** 263-269.
Lievens, F. & Patterson, F. 2011. The Validity and Incremental Validity of Knowledge Tests, Low-Fidelity Simulations, and High-Fidelity Simulations for Predicting Job Performance in Advanced-Level High-Stakes Selection. *Journal of Applied Psychology,* 96**,** 927-940.
Lister, R., Adams, E. S., Fitzgerald, S., Fone, W., Hamer, J., Lindholm, M., McCartney, R., Moström, J. E., Sanders, K., Seppälä, O., Simon, B. & Thomas, L. 2004. A multi-national study of reading and tracing skills in novice programmers. *SIGCSE Bull.,* 36**,** 119-150.
Maj, S. P., Veal, D. & Yassa, L. 2010. A Preliminary Evaluation of the new Cisco Network Security Course. *International Journal of Computer Science and Network Security,* 10**,** 183-187.
McCracken, M., Almstrum, V., Diaz, D., Guzdial, M., Hagan, D., Kolikant, Y. B.-D., Laxer, C., Thomas, L., Utting, I. & Wilusz, T. 2001. A multi-national, multi-institutional study of assessment of programming skills of first-year CS students. *SIGCSE Bull.,* 33**,** 125-180.
McGill, T. & Dixon, M. 2007. Information Technology Certification: A Student Perspective. *Integrating Information & Communications Technologies Into the Classroom.* IGI Global.
Morris, G., Fustos, J. & Haga, W. 2012. Preparing for a Career as a Network Engineer. *Information Systems Education Journal,* 10**,** 13-20.
Peterson, B. K. & Reider, B. P. 2002. Perceptions of computer-based testing: a focus on the CFM examination. *Journal of Accounting Education,* 20**,** 265-284.
Ray, C. M. & McCoy, R. 2000. Why Certification in Information Systems? *Information Technology, Learning, and Performance Journal,* 18**,** 1-4.
Sackett, P. R. 1998. Performance assessment in education and professional certification: Lessons for personnel selection? *In:* Hakel, M. D. (ed.) *Beyond multiple choice tests: Evaluating alternatives to traditional testing for selection.* Mahwah, NJ: Erlbaum.
Stackpole, B., Koppe, J., Haskell, T., Guay, L. & Pan, Y. 2008. Decentralized virtualization in systems administration education. *Proceedings of the 9th ACM SIGITE conference on Information technology education.* Cincinnati, OH, USA: ACM.

Stewart, K. E., Humphries, J. W. & Andel, T. R. 2009. Developing a virtualization platform for courses in networking, systems administration and cyber security education. *Proceedings of the 2009 Spring Simulation Multiconference.* San Diego, California: Society for Computer Simulation International.

Walsham, G. 1993. *Interpreting Information Systems in Organizations*, John Wiley & Sons, Inc.

Wang, X., Hembroff, G. C. & Yedica, R. 2010. Using VMware VCenter lab manager in undergraduate education for system administration and network security. *Proceedings of the 2010 ACM conference on Information technology education.* Midland, Michigan, USA: ACM.

Wästlund, E., Reinikka, H., Norlander, T. & Archer, T. 2005. Effects of VDT and paper presentation on consumption and production of information: Psychological and physiological factors. *Computers in Human Behavior,* 21**,** 377-394.