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An investigation of learning outcomes for MSc programs in Network and System Administration

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What is the essence of a graduate-level system administration education? What skills and abilities of the candidate should educators focus on when developing a new program? This paper investigates the learning outcomes from three MSc graduate programs in network and system administration. We use a tournament-based game as a survey to establish a ranking of all the outcomes from the programs. Our results show a clear emphasis on security and the ability to create working solutions based on abstract descriptions.

Keywords

Network and system administration education, Learning outcomes, Graduate programs, Program development

1. INTRODUCTION

Most aspects of our personal life now have a digital dimension, manifested through a service that is managed by network and system administrators. Be it our finances, travels, medical data or just socializing with our friends and relations. The increase in data-centers, cloud solutions and online e-commerce has opened up more jobs for sysadmins and a demand for professionals with expertise in that field, making it a viable career path for candidates with a computer science degree. In addition, the scale of the services and the complexity of managing them has brought it's own academic field of research and inquiry within computer science. This means research positions and the prospect of PhD-level research within the field. Together, they drive the development of new educational programs that specialize in network and system administration.

There is no single path to becoming a sysadmin. Many have come from a different background and picked up the trade along the way. It is quite common to find that in a group of senior system administrators, only half would have a formal background in something that is related. This trend is changing, however. It is becoming increasingly common to find new employees from computer science graduates.

Over the last decade we have seen multiple educational programs appear, which are based on computer science and that offer a specialization in network and system administration. Students choosing such a program will be targeting the new and growing world of online services and large scale system administration as their career.

While most of the programs available are undergraduate (BSc), there are also graduate (MSc) programs. These offer a specialization for students with a degree in computer science and an opportunity to focus more directly on sysadmin-related topics. From tradition, they also focus more on the development of research skills within the field as students have to complete a thesis to earn their degree.

Developing a new program means writing a proposal for accreditation containing all aspects of the program, such as length, courses, curriculum, acceptance requirements and so on. The accreditation process is essentially the same in all countries as it requires the definition of learning outcomes (or student outcomes) for the student that captures the entire essence of the education [1; 5]. These outcomes inform the student what they can expect to have acquired by successfully completing the program. The courses will also have learning outcomes that reflect back and represent a portion of the program level outcomes. The course requirements and deliverables, such as tests, reports and presentations will assess whether the learning outcomes in fact have been met, validating the "big picture" set out by the program-level outcomes. Program-level outcomes also communicate to the industry what topics they can expect the candidates to be proficient in.

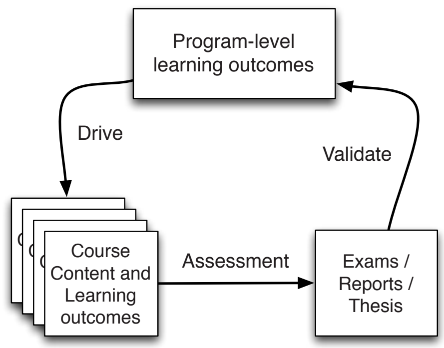

Fig. 1. The learning outcomes defined at the program level drive the learning outcomes, content and type of exercises etc. for the mandatory courses in the program.

In general, developing a program is a top-down process where you look at what overall learning outcomes the student should have and then what courses should cover these. For many established educations, such as teaching, nursing or engineering, the program level outcomes vary to a little degree. When developing a new program of the same topic, one therefore has a body of knowledge to lean on which has gone through accreditation. Today, in the case of a graduate program in system administration, the case is different. There is little comparison and standardization of graduate programs of this kind. This is unfortunate, as it is of little help for educators wanting to develop similar programs at their schools. Also, it makes it hard for the industry to engage in meaningful discussions about curriculum and courses, as they differ from program to program. Having a consensus of what topics would be considered common and constitute a universal kernel across the three programs would hopefully be a starting point for any new programs under development and also facilitate the discussion on whether the outcomes are properly aligned with the currents in the industry.

This article attempts to find what the core topics and goals of a graduate program in network and system administration should be by comparing and ranking the program-level learning outcomes based on three existing programs. The MSc programs at Rochester institute of Technology (Rochester, USA), University of Oslo and the Oslo and Akershus University College of Applied Sciences (Oslo, Norway) and the University of Amsterdam (Amsterdam, The Netherlands) are all examples of graduate programs that have started while the field was still in it's infancy. They were all developed relatively unbeknownst to each other and represent pioneer programs in their respective countries.

Our goal is to identify this kernel in the following steps:

(1) Compare the learning outcomes from all three programs and collect them into a set of outcomes
(2) Attempt a ranking of the outcomes based on the opinions of educators in the field
(3) Conduct a similar ranking based on student's opinions and compare the results with 2

By the end of this exercise, we hope to have found a consensus about what outcomes are considered most relevant to a graduate program in network and system administration.

The rest of the paper is organized as follows: Section 2 provides a brief overview of the three programs and present their learning outcomes. We will collect them into a set and discuss them form our perspective. In section 3 we will explain the methodology for our ranking. Section 4 will summarize the results and attempt to identify the core outcomes followed by a discussion and conclusion in Section 5.

2. BACKGROUND: PROGRAMS AT ROCHESTER, OSLO AND AMSTERDAM

In this section we provide a short overview of the respective programs and list their learning outcomes. As the reader will discover, the outcomes are expressed with similar phrasings and as a continuation of the sentence ”After successful completion, the candidate ...”. The authors have taken the liberty to modify selected outcomes in to singular form in order to improve the reading of them. Also, we have included a list of keywords, so that the reader more easily can extract the essence from each outcome. These keywords are our own attempt to classify the learning outcomes and do not represent any tradition in the development and presentation of learning outcomes.

2.1. Master in Network and System Administration at the University of Oslo and the Oslo and Akershus University College of Applied Sciences, Norway

This two-year program is a collaboration between the University of Oslo and the Oslo and Akershus University College of Applied Sciences. It is a MSc track within computer science that is available to graduates with a computer science or computer engineering degree. The first enrollment into the program was in 2003. Today about 25 students are accepted into the program each year. More information about the program can be found here: [10]

Compared to the other two programs, this has the longest list of learning outcomes. This is due to the local accreditation process in the Norwegian education system. The learning outcomes are to be described in three categories: Knowledge, Skill and General Competence. This increases the number of outcomes since a learning outcome might describe knowledge about a practice and then another would describe the skill of mastering said practice. The outcomes found in the general competence part, are often applicable for many programs, such as the ability to work independently and to complete a research project. In other accreditation bodies, such as ABET, these are embedded in the criteria themselves and do not have to be specified [1]. For the convenience of the reader, we have combined all three categories, since the other programs do not have this distinction.

2.1.1. Learning outcomes. After successful completion of the program, the candidate ...

(1) has thorough knowledge of the professions within network and system administration and their role in businesses, organizations and society
Keywords: Professional development
(2) has a thorough knowledge of the processes and methodologies applied by network and system administrators
Keywords: Processes
(3) has advanced knowledge of how network and system administration is applied at enterprise-scale organizations
Keywords: Processes, Scale, Enterprise
(4) can apply knowledge to new areas within the academic field of network and system administration
Keywords: Innovate, Science
(5) can analyze academic problems within the field of system administration based on its processes, tradition and role in society
Keywords: Analysis, Science
(6) can design and implement scalable and robust service architectures that represent modern and real-life scenarios
Keywords: Scale, Deploy, Industry-relevant
(7) can analyze existing theories, methods and interpretations in network and system administration and work independently on practical and theoretical problems
Keywords: Analysis, Top/Down, Independence
(8) can use relevant methods for research, academic and development work within the field of system administration in an independent manner
Keywords: Independence, Science
(9) can carry out independent research or development projects within the field of system administration under supervision and in accordance with applicable norms for research ethics
Keywords: Independence, Science, Ethics

(10) can apply methods and best practices in the field of system administration in order to evaluate and assess quality in the profession
Keywords: Analysis, Best-Practice
(11) can identify and communicate common facets and challenges within the field of system administration
Keywords:Analysis, Top/Down, Communicate
(12) can deploy, use and manage systems and services that in complexity and scale represent enterprise scenarios
Keywords: Deploy, Manage, Scale, Enterprise
(13) can design IT infrastructures that secure and ensure availability and quality of services and systems
Keywords: Infrastructure, Design, Quality of Service
(14) can analyze relevant academic, professional and research ethical problems in the field of network and system administration
Keywords: Analysis, Ethics
(15) can apply his/her knowledge and skills in new areas in order to carry out advanced assignments in the field of network and system administration
Keywords: Innovate, Learning
(16) can communicate extensive independent work and master the language and terminology of the academic field of network and system administration
Keywords:Communicate, Science
(17) can disseminate academic and professional issues, analyses and conclusions in the field of network and system administration to experts and non-experts alike
Keywords: Communicate, Science, Top/Down
(18) can contribute to new thinking and innovation processes
Keywords: Innovate
(19) has a professional attitude towards his/her field, including an awareness of ethical issues
Keywords: Ethics

2.2. Master in System and Network Engineering at the University of Amsterdam, The Netherlands

This program is offered at the University of Amsterdam and is available to students with a computer science or computer engineering background. Compared to the other two programs, this is a single-year track, however with a three-semester model. This makes it a rather intensive program, but students have reported a positive attitude towards this model, as it enables them to enter professional life earlier. The first year of enrollment was 2003 and today about 30 students are accepted each year. The contents and organization of the Amsterdam and Oslo program have perviously been discussed by Burgess and Koymans[3]. More information about the program can be found here: [11]

The number of learning outcomes are fewer compared with Oslo, but they contain many of the same keywords.

2.2.1. Learning outcomes. After successful completion of the program, the candidate ...

(1) has knowledge on an abstract level of the operation of computers and networks with respect to interfaces, protocols and software
Keywords: Top/Down, Network, Systems
(2) is able to translate abstract knowledge into concrete system and network configurations, independent of underlying vendor technology
Keywords: Top/Down, Network, Systems, Configure
(3) is able to acquire knowledge about innovative technologies and evaluate their potential
Keywords: Analysis, Learning

(4) is able to become acquainted with research methods in the domain within a short period of time and are able to apply these
Keywords: Learning, Science, Utilize
(5) is able to accommodate research innovations in an evolutionary way into existing systems
Keywords: Science, Utilize
(6) is familiar with the philosophy and practice of Open Technology and are able to evaluate its strength and possibilities in relation to proprietary technology
Keywords: Critical, Open Source
(7) is able to build innovative systems using Open Components
Keywords: Innovate, Configure, Deploy, Code
(8) is familiar with the ethical and juridical aspects of their research
Keywords: Science, Ethics
(9) is able to recognize security aspects of systems on all levels and to take adequate measures to eliminate security problems where needed
Keywords:Security, Top/Down

2.3. Master in Networking and Systems Administration at Rochester Institute of Technology, USA

This two-year program is offered at Rochester Institute of Technology in USA which also offers an undergraduate program with the same topic. Compared to the two other programs, this offers distinct tracks for students to take based on their preference. They are named *knowledge domains*, which are Management, Professional and Research. In addition, students can chose between a project or thesis option where they either complete a technical project or a more scientifically oriented thesis. First enrollment into this program was in 2007 and 17 students are estimated to begin in 2015. More information about the program can be found here: [6]

2.3.1. Learning outcomes. After successful completion of the program, the candidate ...

(1) will be able to describe technologies emerging in the field of networking and system administration and their impact on large organizations
Keywords: Top/Down, Communicate
(2) will be able to be a key contributing member in the development, management, or research of the computing infrastructure of an enterprise
Keywords: Code, Manage, Science, Infrastructure, Enterprise
(3) will be able to describe and implement technologies important to the management and deployment of large scale computing environments
Keywords: Communicate, Deploy, Configure, Scale
(4) will be able to interface and communicate effectively at all levels of an organization
Keywords: Communicate, Top/Down, Organization
(5) will be able to design and write effective computer and network policies that meet the operational and business goals of their organizations
Keywords: Communicate, Policy, Organization
(6) will be prepared to participate effectively in research positions, leadership positions, or professional careers in computing in both private and public sectors, or alternatively, for admission to other academic programs
Keywords: Science, Professional development

2.4. Comparison of learning outcomes

As all programs are well-established and have passed local quality assurance processes, there are no inappropriate or irrelevant learning outcomes. Every outcome is clearly a part of what one would consider valuable knowledge and skills for a career in system administration. However, we are interested in the relationship between them. When developing a program from its outcomes, it is

Rank	Score	Respondent 1	Respondent 2	Respondent 3	Respondent 4
1	4	C2	C1	C2	C3
2	3	C1	C2	C3	C2
3	2	C3	C3	C4	C1
4	1	C4	C4	C1	C4

Final ranking based on average score	
C2	3.50
C3	2.75
C1	2.50
C4	1.25

Fig. 2. This illustration shows an example of the tournament game. Every respondent completes one tournament, ranking the contestants C1 to C4. Every rank position is awarded a score which is collected and averaged to calculate the final ranking.

challenging to balance the amount of time spent on each outcome. Which one is more important? Where should the focus be?

There seem to be some keywords that are emphasized more at different programs. For example, at Rochester, the ability to communicate, participate and be a productive member is visible. At the Amsterdam program, Open Technology, Open Components and vendor independence is mentioned, which is not present in the other two. The Oslo program contains outcomes that speak to the ability to work independently, ethically and with a professional attitude, which stem from the learning outcomes in the general competence category.

3. SINGLE-ELIMINATION TOURNAMENTS FOR IMPORTANCE RANKING

The predictive power of tournaments is widely studied. This paper does not intend to summarize the wealth of knowledge accumulated in the field of statistics and all applications of tournaments and their varying formats. A good investigation into the relationship of noise and the predictive power of elimination tournaments has been done by Ryvkin et. al. [7; 9; 8]

In order to provide a ranking of all the outcomes, a pseudo single-elimination tournament-style game was developed as a form of web-based survey. In the tournament, all learning outcomes are seeded into rounds of matches. A survey respondent will be faced with a series of single matches with the text ”Which of the two learning outcomes is the most important for a MSc programme in network and system administration?”. The respondent must decide which of the two presented outcomes is the most important by clicking on it. The designated important is considered a ”winner” in the match and moves on to meet another winner from the same tournament round. The whole survey resembles that of a tournament, where the final winner is the one that has consistently been deemed most important by the respondent. In addition, all ”losers” are not immediately eliminated, but have to compete against other losers and so on. An example of this is in the soccer world cup or the Olympics Games, where the 3rd place is determined by the two semi-final losers. By including this process for all the losers, the result is a complete ranking where all the initial contestants will end up with a position. For example, the losers of the first round of matches compete for the bottom half of the positions. At the end of a tournament, each position is awarded with a score, the highest ranking getting the highest score. Since each respondent completes one tournament, all the scores will be collected into a cumulative score where the learning outcomes with a consistent high ranking will end up with a high total score.

The above described ranking system was implemented as a web-based survey. Individual match data as well as scores of the tournaments were stored in a database for later analysis. For practical reasons, a seed setting was included, since these tournaments made most sense when the number of contestants were in the power of two (4,8,16 and so on). In the case where the number of contestants was not the power of two, one could pick a seed that would be close, like 8 in the case of 11 contestants. In that case, every tournament would start with a random 8 from the original 11. The downside of this is that one does not fully control the number of tournaments every contestant participates in.

4. LEARNING OUTCOME RANKING BASED ON EDUCATORS AND STUDENT OPINIONS

During the 2014 USENIX Summit for Educators in System administration (SESA14), the participants were asked to complete such a tournament each with the results collected for this study. The summit represents a unique venue for educators and industry representatives to discuss and present topics with regard to education of system administration. The audience at SESA 14 were selected as an expert group for our survey, representing an international community of educators and industry participants who all have an expressed interest in system administration education by virtue of being present at SESA 14. All the learning outcomes from the three programs amount to 34, so a seed of 32 was chosen. This means that every participant only had a tournament of 32 learning outcomes, which was a considerable task with many individual matches. 13 anonymous tournaments were completed, which is 81.25% of the people present at SESA during the exercise. A total of 977 individual matches were registered.

A similar exercise was conducted on a class of 2nd year master students at the program in Oslo. The difference from the SESA14 group was a much lower seed, only 16. The reasoning for this was that since the students were asked via email to complete a tournament each, it was more unlikely that they would complete all the matches and end up with incomplete results. A total of 16 tournaments were completed with a total of 458 individual matches.

4.1. Ranking Results from SESA14

In order to analyze the results we will attempt to identify clusters of topics or outcomes if outcomes of similar phrasings are located close to each other and with similar scores. The resulting list of clusters or topics would hopefully reveal a clearer image of how the topics rank relative to each other.

Table I shows the top 16 outcomes. After the outcome and it's keywords, we see the average score attained by this outcome.

On top is a learning outcome describing the ability to recognize security aspects on all levels and apply needed measures, is the only learning outcome that describes security. The maximum score is 32, so an average of 25.7 is considered to be high. This is echoed by the median of the tournament positions. As this outcome was part of 9 tournaments (last column), it ended up in the top 6 half of those times. A closer inspection shows that it's lowest position in a tournament was 14. This learning outcome is interesting as it is the only one with *security* as a keyword. Security is a major topic within the field of system and network administration and it's high score makes sense.

On second place is a learning outcome that describes the ability to go from an abstract design to a concrete implementation. It captures, besides security, a major part of system administration as it involves many skills, such as abstract reasoning, service design, deployment, installation and configuration. Furthermore, it involves the ability to fill in the details that are omitted by the abstract description, which requires broad knowledge about local policies and technologies. It is, in a sense, the part of the job that ”only the system administrator can do” and overlaps very little with other jobs. The outcome is also unique and is the only *Top/Down* item that describes a technical task, the other ones are mainly about analysis and communication. It is understandable that this item got a high score, quite comparable with the first position with an even better median but a marginally lower average.

On the positions 3 and 4 we see two learning outcomes that both contain the keyword *Scale* and *Enterprise*. They describe advanced knowledge and the deployment of enterprise-scale services. Two other learning outcome contain *Scale*, which are on position 7 and 8 with a slightly lower average score but similar median. These four can arguably be grouped together under an ”Enterprise-scale” umbrella.

The learning outcomes on positions 5,6,9 and 10 are differently phrased but all speak about non-technical skills, such as designing services, understanding and assessing processes and best-practice.

Table I. Ranking results from SESA14, position 1 - 16

Position	Learning Outcome	Keywords	Avg. Score	Position median	Win percentage	Tournaments played
1	is able to recognize security aspects of systems on all levels and to take adequate measures to eliminate security problems where needed	Security, Top/Down	25.7	6	60.4	9
2	is able to translate abstract knowledge into concrete system and network configurations, independent of underlying vendor technology	Top/Down, Network, Systems, Configure	25.5	5	62.5	11
3	can deploy, use and manage systems and services that in complexity and scale represent enterprise scenarios	Deploy, Manage, Scale, Enterprise	23.6	8	62.9	11
4	has advanced knowledge of how network and system administration is applied at enterprise-scale organizations	Processes, Scale, Enterprise	22.8	8	62.3	12
5	can design IT infrastructures that secure and ensure availability and quality of services and systems	Infrastructure, Design, Quality of Service	22.3	8	73	12
6	can apply methods and best practices in the field of system administration in order to evaluate and assess quality in the profession	Analysis, Best-Practice	21	9	66.1	11
7	can design and implement scalable and robust service architectures that represent modern and real-life scenarios	Scale, Deploy, Industry-relevant	20.9	7.5	66	10
8	will be able to describe and implement technologies important to the management and deployment of large scale computing environments	Communicate, Deploy, Configure, Scale	20.6	8	67.7	13
9	can apply knowledge to new areas within the academic field of network and system administration	Innovate, Science	20.5	11	61.8	11
10	has a thorough knowledge of the processes and methodologies applied by network and system administrators	Processes	20.2	10	60.7	11
11	can apply his/her knowledge and skills in new areas in order to carry out advanced assignments in the field of network and system administration	Innovate, Learning	19.8	9	64.6	13
12	is able to acquire knowledge about innovative technologies and evaluate their potential	Analysis, Learning	19.8	11	54.9	9
13	can analyze existing theories, methods and interpretations in network and system administration and work independently on practical and theoretical problems	Analysis, Top/Down, Independence	19.7	11	59.2	9
14	will be prepared to participate effectively in research positions, leadership positions, or professional careers in computing in both private and public sectors, or alternatively, for admission to other academic programs	Science, Professional development	17.8	14	51.7	11
15	can use relevant methods for research, academic and development work within the field of system administration in an independent manner	Independence, Science	16.1	15	48.3	12
16	will be able to be a key contributing member in the development, management, or research of the computing infrastructure of an enterprise	Code, Manage, Science, Infrastructure, Enterprise	15.6	17	52.3	13

One could loosely describe them as tasks related to technical work and not to communication skills, as *Communication* is not mentioned in them. We could translate their general essence into ”Processes” and ”Service Management”.

The following 8 outcomes (11 to 17) are not very specific to system administration, as it details general traits of a successful student: to work independently and also be a good team-member, to be a good learner and to master advanced problems and theories. There are mentions of career options as well as academic work. The medians here are sinking gradually and we are at the point that could be described as the middle of the pack. The outcomes mostly win more than they loose, and in singular cases they end up on top. For example, number 14 actually came 1st in one tournament. It is more difficult to group these learning outcomes into one category, but what they have in common would be a trait usually associated with someone who has experience from a graduate program, namely the increased independent work, more theoretical tasks and overall increased level of difficulty. We therefore chose the term ”Academic proficiency” as a generalization.

The results continue on Table II. Outcomes from number 18 to 23 are less specific towards system administration. They seem to end up with a lower score than the ones that point to specific problems in the field, such as enterprise-scale services or security. However, it is interesting that most of them are about communication and interfacing with the organization. This is what is commonly described as ”soft skills”, although the above group may arguably be called a soft skill too. It is interesting to note how communication seems to cluster together like in Table II. As pointed out earlier, the fact that they have a low score does not make them irrelevant in a program, but it is clear here that the more concrete the learning outcome to the core of system administration, the more likely it is to be identified as more important than to ”be able to interface and communicate effectively at all levels of an organization”.

In a broad sweep, we will group the remaining outcomes into ”Scientific work”. With very few exceptions, we find the keywords *Science*, *Analysis*, *Innovate* and *Ethics* here. This is where we find the ability to become acquainted with research methods, conduct research by trying out new ideas and innovate as well as communicating results to the public.

4.2. Ranking results for MSc students at Oslo

These results have generally less data due to the smaller seed for each tournament. Also, the maximum attainable score from a tournament was now 16, so the averages seem at first lower, although they should not be interpreted as such.

The results form Tables III and IV are not well aligned with the SESA14 results, but there are some similarities. By comparing the student rankings with those from SESA14, we discover that about 80% of the outcomes end up 8 positions or less apart in the two tables. The median distance between an outcome’s ranking in the two tables is 6. There are a few cases where the distance is large, for example number 20, which is the second ranked outcome in the SESA14 table. The details about this learning outcome in this exercise are that it has participated in only 7 tournaments and ended on the positions 3, 5 (twice), 7, 11, 13 and 14.

These results do not give themselves to clustering the same way, due to the fewer number of matches and the fact that most outcomes have participated in fewer tournaments with less then half of the other outcomes. However, we can recognize some of the trends from the topic ranking from before. We see, for example, that the top 5 learning outcomes all address deployment, configuration and management of systems and services on an enterprise scale. The bottom of the ranking also repeats the same keywords, such as *Ehtics* and *Science*. We interpret the results that they show the same start and end as the SESA14 data, but do not identify strong clusters in the middle.

4.3. Identifying the core role of the MSc graduate

The tournament exercise revealed clusters in the 34 learning outcomes in the SESA14 data. Based on our analysis the order of the topics is as follows:

(1) Security
(2) Translating abstract descriptions into actual implementations
(3) Enterprise-scale
(4) Service Management and Processes
(5) Academic Proficiency
(6) Communication skills
(7) Scientific work

Table II. Ranking results from SESA14, position 17 - 34

Position	Learning Outcome	Keywords	Avg. Score	Position median	Win percentage	Tournaments played
17	has knowledge on an abstract level of the operation of computers and networks with respect to interfaces, protocols and software	Top/Down, Network, Systems	15.5	18.5	52.9	10
18	will be able to interface and communicate effectively at all levels of an organization	Communicate, Top/Down, Organization	15.3	20	47.6	12
19	will be able to design and write effective computer and network policies that meet the operational and business goals of their organizations	Communicate, Policy, Organization	15.0	13	44.1	11
20	can disseminate academic and professional issues, analyses and conclusions in the field of network and system administration to experts and non-experts alike	Communicate, Policy, Organization	14.9	20	50	11
21	is familiar with the philosophy and practice of Open Technology and is able to evaluate its strength and possibilities in relation to proprietary technology	Critical, Open Source	14.8	15	39.7	11
22	will be able to describe technologies emerging in the field of networking and system administration and their impact on large organizations	Top/Down, Communicate	14.3	17	53.6	11
23	has thorough knowledge of the professions within network and system administration and their role in businesses, organizations and society	Professional development	13.7	16.5	39.6	10
24	has a professional attitude towards his/her field, including an awareness of ethical issues	Ethics	13.3	22	37.3	11
25	can identify and communicate common facets and challenges within the field of system administration	Analysis, Top/Down, Communicate	12.8	15	40.8	9
26	can carry out independent research or development projects within the field of system administration under supervision and in accordance with applicable norms for research ethics	Independence, Science, Ethics	11.8	21	45	11
27	can analyze academic problems within the field of system administration based on its processes, tradition and role in society	Analysis, Science	11.6	20	32.1	10
28	can analyze relevant academic, professional and research ethical problems in the field of network and system administration	Analysis, Ethics	11.5	19	39	11
29	can communicate extensive independent work and master the language and terminology of the academic field of network and system administration	Communicate, Science	11.3	21	44.6	11
30	can contribute to new thinking and innovation processes	Innovate	10.8	23	35	12
31	is able to become acquainted with research methods in the domain within a short period of time and are able to apply these	Learning, Science, Utilize	10.5	22	36.2	11
32	is able to build innovative systems using Open Components	Innovate, Configure, Deploy, Code	9.8	21.5	25.8	12
33	is familiar with the ethical and juridical aspects of their research	Science, Ethics	7.8	25	25.5	9
34	is able to accommodate research innovations in an evolutionary way into existing systems	Science, Utilize	6.7	27.5	33.3	10

Table III. Ranking results from students, position 1 - 16

Position	Learning Outcome	Keywords	SESA14 pos.	Avg. Score	Position median	Win percentage	Tournaments played
1	can design and implement scalable and robust service architectures that represent modern and real-life scenarios	Scale, Deploy, Industry-relevant	7	11.1	3	71	7
2	can deploy, use and manage systems and services that in complexity and scale represent enterprise scenarios	Deploy, Manage, Scale, Enterprise	3	11	3	75	3
3	has advanced knowledge of how network and system administration is applied at enterprise-scale organizations	Processes, Scale, Enterprise	4	10.8	4.5	69.2	6
4	will be able to describe and implement technologies important to the management and deployment of large scale computing environments	Communicate, Deploy, Configure, Scale	8	10.8	6	61.9	5
5	can design IT infrastructures that secure and ensure availability and quality of services and systems	Infrastructure, Design, Quality of Service	5	10.5	3.5	55.6	6
6	will be prepared to participate effectively in research positions, leadership positions, or professional careers in computing in both private and public sectors, or alternatively, for admission to other academic programs	Science, Professional development	14	10.5	4	72.2	4
7	can disseminate academic and professional issues, analyses and conclusions in the field of network and system administration to experts and non-experts alike	Communicate, Policy, Organization	20	10.2	5.5	62.1	6
8	is able to recognize security aspects of systems on all levels and to take adequate measures to eliminate security problems where needed	Security, Top/Down	1	9.9	4	50	7
9	can apply his/her knowledge and skills in new areas in order to carry out advanced assignments in the field of network and system administration	Innovate, Learning	11	9.6	6	52.4	5
10	will be able to be a key contributing member in the development, management, or research of the computing infrastructure of an enterprise	Code, Manage, Science, Infrastructure, Enterprise	16	9.5	7	64.4	11
11	has a professional attitude towards his/her field, including an awareness of ethical issues	Ethics	24	8.7	6	41.4	7
12	has thorough knowledge of the professions within network and system administration and their role in businesses, organizations and society	Professional development	23	8.7	7	54.8	7
13	can apply methods and best practices in the field of system administration in order to evaluate and assess quality in the profession	Analysis, Best-practice	6	8.7	8	48.3	7
14	can use relevant methods for research, academic and development work within the field of system administration in an independent manner	Independence, Science	15	8.6	7	60	5
15	will be able to design and write effective computer and network policies that meet the operational and business goals of their organizations	Communicate, Top/Down, Organization	19	8.6	8	54.3	7
16	can apply knowledge to new areas within the academic field of network and system administration	Innovate, Science	9	8.5	7.5	55.2	6

Table IV. Ranking results from students, position 17 - 34

Position	Learning Outcome	Keywords	SESA14 pos.	Avg. Score	Position median	Win percentage	Tournaments played
17	can identify and communicate common facets and challenges within the field of system administration	Analysis, Top/Down, Communicate	25	8	7	45.5	5
18	is familiar with the philosophy and practice of Open Technology and are able to evaluate its strength and possibilities in relation to proprietary technology	Critical, Open Source	21	8	8	42.9	5
19	will be able to interface and communicate effectively at all levels of an organization	Communicate, Top/Down, Organization	18	8	10	51.6	7
20	is able to translate abstract knowledge into concrete system and network configurations, independent of underlying vendor technology	Top/Down, Network, Systems, Configure	2	7.7	7	54.8	7
21	can analyze existing theories, methods and interpretations in network and system administration and work independently on practical and theoretical problems	Analyze, Top/Down, Independence	13	7.4	7	48.4	7
22	has a thorough knowledge of the processes and methodologies applied by network and system administrators	Processes	10	7.3	9	53.3	3
23	can analyze relevant academic, professional and research ethical problems in the field of network and system administration	Analysis, Science	28	7	8	41.9	7
24	is able to acquire knowledge about innovative technologies and evaluate their potential	Analysis, Learning	12	7	8.5	51.4	8
25	is able to build innovative systems using Open Components	Innovate, Configure, Deploy, Code	32	6.8	10	42.9	5
26	can contribute to new thinking and innovation processes	Innovate	30	6.1	12	35.9	9
27	is able to become acquainted with research methods in the domain within a short period of time and are able to apply these	Learning, Science, Utilize	31	6	10.5	38.5	6
28	is able to accommodate research innovations in an evolutionary way into existing systems	Science, Utilize	34	6	11	35.3	4
29	will be able to describe technologies emerging in the field of networking and system administration and their impact on large organizations	Top/Down, Communicate	22	5.8	11	52.6	4
30	can communicate extensive independent work and master the language and terminology of the academic field of network and system administration	Communicate, Science	29	5.4	12	39.6	11
31	can carry out independent research or development projects within the field of system administration under supervision and in accordance with applicable norms for research ethics	Independence, Science, Ethics	26	5.2	12	38.1	5
32	has knowledge on an abstract level of the operation of computers and networks with respect to interfaces, protocols and software	Top/Down, Network, Systems	17	4.6	16	37	5
33	can analyze academic problems within the field of system administration based on its processes, tradition and role in society	Analysis, Science	27	4.2	13	33.3	5
34	is familiar with the ethical and juridical aspects of their research	Science, Ethics	33	3.2	13.5	24	6

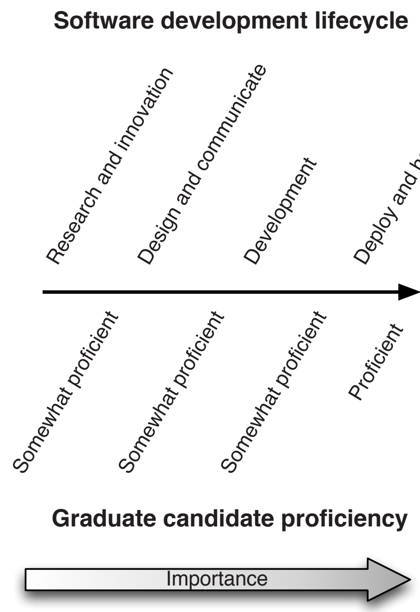

Fig. 3. A graduate level education in system administration is expected to provide some proficiency in many phases of a software development. During the final stages the expertise of the system administrator becomes more essential and is awarded more importance in the ranking.

It is interesting to see how the list goes from practical and concrete to the theoretical, underlining the focus of being a profession-oriented education. Security came on top because the only learning outcome with a security focus also got the highest average score. With more learning outcomes with a similar focus, we could have seen if the result would be consistent. In the case where there were several outcomes of the same topic we found that they ended up in proximity to each other.

Considering the ranking of the topics we can build a better understanding of where a candidate should be useful and expected to contribute. In a modern software lifecycle there are several phases where we find learning outcomes in our table that are applicable. There is research and innovation, design and communication, development and finally deployment and hardening. None of the learning outcomes can be omitted, so a certain proficiency in all fields can arguably be expected to some degree of a graduating candidate. But with other programs specializing in the earlier stages of the lifecycle system administrators would most likely only form a part of a team. In the deployment and stage, it is the expertise of the system administrator that is essential and requires them to be proficient to a higher degree on these areas than the preceding ones, See Figure 3.

Again, we need to stress that none of the outcomes and topics should be considered *unimportant*. The total spectrum of the learning outcomes showcase that the system administrator is expected to function as a team member in many areas.

5. DISCUSSION

During discussions at USENIX SESA or Sysadmin Education Workshop at the USENIX Large Installation System Administration conference, we find that many of the skills and knowledge presented in the learning outcomes resonate with what is considered important. However, there are two items which are missing: maintenance and troubleshooting. Undoubtedly, they make up a portion of a system administrators tasks, why are they not mentioned in the learning outcomes? In Figure 3, the software development lifecycle stops at deployment while every system administrator would argue that there is still a long path ahead after that with maintenance, monitoring and troubleshooting.

One explanation is that they might be considered "helper subjects" that are not a topic in themselves but rather taught indirectly as part of lab work and exercises. However, there are some examples of maintenance tasks that in nature are so complex that certain strategies could be taught and discussed explicitly. One case in point is a rolling upgrade of many servers with a fail-over strategy. Another explanation for not focusing on troubleshooting and maintenance in the learning outcomes is that they could be considered something that needs to be taught at bachelor level, such as undergraduate elective system administration classes. However, this is not a given, as such courses are not available at all schools. It is not unlikely that a student completing one of the three programs mentioned here had no previous system administration courses as part of their undergraduate degree. Looking at undergraduate programs, such as the one at the University College of Gjøvik, we identify courses that address troubleshooting and maintenance to a larger degree[4]. Still, the authors believe that inclusion of these two topics should be discussed further in the future.

One could ask if a MSc graduate is a suitable candidate for a system administration position where the main tasks would be to maintain a small number of servers in a SMB context? Our results suggest otherwise. The fact that enterprise and scale were two important keywords, indicate that the SESA14 audience considered the candidates to be fit for larger and more complex environments where perhaps the approaches and solutions are not straight forward. If so, can a line be drawn between undergraduate system administration programs and graduate ones as to the scale and complexity of the infrastructure? Does the problem scope of a SMB infrastructure represent a good base for an undergraduate students, where certain skills and knowledge still needs to be acquired? Does teaching research and inquiry fit the more dynamic and complex problems of enterprise scale infrastructure? Our data do not answer this question, they merely help formulate it. Still, for us this question raises important points about how the profession and its practice can be properly aligned with the different program levels and will have to be investigated further.

Learning outcomes that spoke of programming scored low in importance. We believe this is because a background in computer science will mean that programming proficiency is present. The student is, in other words, expected to know how to write software and apply that knowledge in an operations setting, meaning scripting and automation. We find that automation combined with the ability to go from abstract to working solution is the basis for building modern platforms for services, such as continuous delivery frameworks and devops. The latter also includes insight into processes and service management, which is present in the learning outcomes as well. This is interesting, as a current trend in service architectures is that of the immutable infrastructure with clouds and containers[2], where software is not *maintained* in the typical sense, but simply re-deployed with a newer version.

The fact that the outcomes of similar topics ended up grouped together indicate that the ranking was rather consistent. This can at least be said for the top and bottom of the results. Also, the clear transition of topics from the concrete to the abstract can be interpreted that there is general consensus amongst the respondents that succeeding at the concrete and practical tasks is most important. SESA14 consisted of academics and members of the industry but the distinction was not recorded in the data. One could raise the question if there is even more consensus should we divide industry and academia into sub-groups. A future study with more targeted audiences would help clarify this. Still, we hope our findings and method can facilitate the development of future programs of the same kind by offering input into what outcomes should be included and were focus should be placed.

5.1. Future work

The authors plan to investigate the students opinions further, as there results did not yield as clear clusters as the SESA14 data. One approach would be to repeat the survey with the same seed (32) as for SESA14 and for students on all three programs. This would help us look for local differences in expectancies and provide more data for analysis. If the number of matches would make it impractical, a more condensed tournament consisting only of the keywords would also be possible.

6. CONCLUSION

This paper investigated the learning outcomes from three MSc programs in network and system administration. Our ranking experiment showed an order of importance that values security and the ability to deliver working solutions from abstract descriptions the highest. Theoretical work and ”soft skills” were lowest ranked. Our results suggest that there is consensus amongst experts as to what constitutes the essence of system administration.

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