ENTRY COMPETENCES ASSESSMENT OF DATA SCIENCE POTENTIAL STUDENTS

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Abstract

The past two decades are characterized by a tremendous growth of the amount of data generated and recorded in computer repositories. To learn and benefit of accumulated data, people need to use Information Technologies to retrieve, process, analyze and explore huge amount of data. Consequently, terms such as Big Data, data analytics, machine learning, deep learning, etc. appeared to mark the dependence of practically all aspects of human life on data and on instruments to explore data. The term Data Science represents in the best possible way the complexity and comprehension of expertise needed nowadays. Developing competences and training professionals in this field represents a significant challenge to educational institutions. Professionals in the field of Data Science, known as Data Scientist, need to possess competences in various areas such statistics, informatics, computing, communication, management, sociology, economics, etc. Data Science has thus emerged as an inter, multi and even transdisciplinary area of knowledge.

Many authors investigate the range of competences, knowledge and skills a Data Scientist need to master. Although in many cases the focus is on technical skills, working with data requires mastery of a huge variety of skills and abilities. In fact, a combination of analytical, statistical, algorithmic, engineering, and technical skills have to be possessed to mine relevant data by involving contextual domain information. In previous studies, we have shown that analytical competences represent the cross-point of all other hard (technical) and soft (non-technical e.g. communication, collaboration, curiosity etc.) skills, especially in the Big Data context. For building such competences, a certain level of maturity and experience is essential and graduate level is the natural choice in building educational programs to train Data Scientists. Many factors may influence success of a graduate program in such complicated field. Among the rest, we consider assessment of students' entry background as essential. The analytical thinking expertise may serve as the key for students, coming from different Bachelor degree programs, to succeed in a Data Science Master program.

The paper shares development of a questionnaire to assess the analytical thinking among the current students in IT-related bachelor degree programs. Motivated by the aims listed above, the research addresses the following questions:

1 Do prospective students have substantial analytical skills to study Data Science Master program?

2 Can we reveal the potential success that students could achieve as analysts when they graduate?

3 Can we improve the Data Science master program to achieve shifting educational patterns and analytical thinking development?

We have examined principles of analytical thinking, many relevant tests such as existing assessments of analytical thinking, critical thinking, problem solving skills tests, etc. The main part of the questionnaire constructed is consisted from logical problems in three different formats: math questions, text assignment and figures pattern recognition. It also includes two questions which measure how students themselves rate their analytical thinking skills and dispositions.

Keywords: Data Science, Data Scientist's skills, analytical skills, analytical thinking assessment.

1 INTRODUCTION

Over the past two decades the Internet of Things (IoT) and Web 2.0 technologies has been contributed to the tremendous growth in the amount and variety of the data generated – the phenomenon of Big Data. The recognition of the potential of exploring and learning from accumulated data established the field of Data Science. As the information contained in it must be extracted, currently big data and data analytics have been the subject of considerable discussion.

Analyzing Big Data allows analysts, researchers, and business users to make better and faster decisions based on tight data-based insights rather than intuition or experience [32]. The advancements of tools and techniques for collecting, preprocessing and analyzing Big Data have resulted in a new interdisciplinary domain called Data Science, which utilizes the knowledge developed in areas such as statistics, informatics, computing, communication, management, and sociology [18,30,33]. Cleveland proposed Data Science as an independent field of study [34].

Especially in recent years, the need for people who are fluent in working with data has grown exponentially. Those professionals who make insights from data by analyzing it are often called Data Scientists in the literature. Davenport and Patil published a well-known article concerning the competency of data analysts titled “Data Scientist: The Sexiest Job of the 21st Century”[31]. However the McKinsey Global Institute claims that the U.S. economy could be short as many as 250,000 data scientists by 2024 [15].

Many authors investigate the Data Scientist’s wide range of competencies and challenges they are faced [7,10,11,28]. The recursive data cycle of obtaining, wrangling, curating, managing and processing data, exploring data, defining questions, performing analyses and communicating the results lies at the core of the Data Science experience [19].

Although in many cases when evaluating essential Data Scientist’s competencies, the focus is on technical skills, working with data requires the mastery of a variety of skills and abilities. In fact, a combination of analytical, statistical, algorithmic, engineering, and technical skills have to be possessed to mine relevant data by involving contextual information. In previous studies, we have shown that analytical competences represents the cross-point of all other hard (technical) and soft (non-technical e.g. communication, collaboration, curiosity etc.) skills in data processing, especially in the Big Data context [10,11]. As data analytics is a keystone of Data Science, this paper is focused on assessment of analytical competences of students, and some topical issues.

For building such competences a certain level of maturity and experience is essential and graduate level is the natural choice in building educational programs to train Data Scientists. Many factors may influence success of a graduate program in such complicated field. Among the rest, we consider assessment of students’ entry background as essential. The analytical thinking expertise may serve as the key for students, coming from different Bachelor degree programs, to succeed in a Data Science Master program.

From one side, we recognize analytical thinking as an indicator for readiness of a student to complete successfully the program, but from another – assessment of background of potential students plays critical role in designing practically the any component of the program – from selection of courses, scheduling, balancing between theory and practice, and selecting specific pedagogical techniques to engage students in learning and mastering skills.

Research reported in this article is a part of a large-scale research project examining Data Scientist’s analytical skills. It seeks to address the following questions:

1 Do prospective students have substantial analytical skills to study Data Science Master Program?

2 Can we reveal the potential success that students could achieve as analysts when they graduate?

3 Can we improve the Data Science Master Program to achieve shifting educational patterns and analytical thinking development?

The aim of this paper is to share experience in developing a questionnaire to assess the analytical thinking skills of current students in IT-related bachelor degree programs. To achieve this goal we have focused on principles of analytical thinking and investigated many relevant tests such as existing assessments of analytical thinking, critical thinking, problem solving skills tests, etc. The constructed questions represent logical problems in three different formats: math questions, text assignment and figures pattern recognition. The questionnaire also includes two questions which measure how students themselves rate their analytical thinking skills and dispositions.

This paper has been divided into four sections. The first section presents an overview of Data Science related challenges and also the aim of our paper. The second part details the methodology that was used in this study. The third section present constructed questionnaire to assess the analytical thinking skills. Finally, fourth section discusses the results of the study and offers concluding remarks.

2 ANALYTICAL THINKING ASSESSMENT: PRINCIPLES AND PRACTICES

2.1 Analytical thinking as a core competency

Sternberg and Grigorenko [22,23] divided thinking skills into 3 categories: analytical, creative and practical thinking, and analytical thinking involves the processes of knowledge-based problem solving and decision-making. Robbins claims that both analytical and logical thinking skills are necessary when solving problems [8]. Analytical / critical thinking is often associated with directed thinking, i.e. solving problems, seeking the truth and developing understanding, with the focus on a desired outcome [26,27]. Being linked to one another critical, logical, and analytical skills often are presented in the literature as overlapped issues largely [11].

The ability to think logically, analytical thinking and critical thinking are very useful in activities such as decision making, issue analysis, inquiry, problem solving and self-assessment. Critical thinking is thinking act based on knowledge, available evidence, exploration and information to arrive at a reasonable conclusion. Halpern defines critical thinking as "the use of cognitive skills or strategies that increase the probability of a desirable outcome"[4]. Analytical thinking is necessary when an ambiguous situation requires the learner to identify or create a problem to solve. On the other hand, analytical thinking have some special features:

- It proceeds systematically, step by step, to identify, separate and evaluate the components of a complex situations, practices, problems, statements, ideas, theories, arguments.
- It identifies relations of priority, hierarchy, cause and effect.
- It uses tools for analysis, redefining the situation in doing so, and for presenting conclusions.

Researcher considers analytical thinking abilities includes [5,17,20]:

- Analyzing argument, claims, or evidence.
- Making inferences using inductive or deductive reasoning.
- Judging or evaluating.
- Making decisions or solving problems.

The last four decades have seen the transfer of data analysis on small and simple data, along with hypothesis testing, to data analytics on large and complex data for hypothesis-free knowledge and insight discovery. That is what we call Data Science. It involves principles, processes, and techniques for understanding phenomena via the (automated) analysis of data [6]. To perform analysis, Data Scientist needs to understand: what problem he/she needs to solve; what kind of answers he/she is trying to find by solving the problem; present information available about the problem; sources of information; reliability of information; interrelationships - the rules/laws governing the problem; problem formulation, complexity of the problem; problem solving methodologies and complexities, and representation of solutions to find answers to the questions posed earlier etc. [29].

In previous studies, we have shown that Data Scientist's analytical competences represents the cross-point of all other hard (technical) and soft (non-technical e.g. communication, collaboration, curiosity etc.) skills, especially in the Big Data context. Similarly, the analytical competences are the primary focus of the current study. Our paper suggest that individuals who exhibit skills in analytical and logical thinking are also more inclined to be successful in a Data Science Master program.

Analytical thinking competency encompasses a set of abilities whose development begins within families and at each education stage, students maintain and enhance competencies from previous stages. The basic disciplines such as Mathematics, Statistics, Programming etc. included in a regular IT program develop these competencies.

In the literature the issue of analytical skills is closely related to Benjamin Bloom's classification of cognitive skills and learning behavior [1]. Nowadays Bloom's taxonomy is widely seen as taxonomy for information processing skills and it is often used when designing educational, training, and learning processes. It classifies thinking according to six cognitive levels of complexity: knowledge, comprehension, application, analysis, synthesis, and evaluation. The categories are ordered from simple to complex and from concrete to abstract, each level must be mastered before moving to the next higher level. The three highest levels (analysis, synthesis, and evaluation) are frequently said to represent analytical thinking [14].

Table 1. Bloom's Taxonomy.

Level	Description	Keywords
Knowledge	Remember previously learned information.	Who? What? Find, Define, Recall
Comprehension	Demonstrate an understanding of the facts.	Compare, Contrast, Explain, Discuss
Application	Apply knowledge to the new situation.	Plan, Build, Experiment, Design, Solve, Interview
Analysis	Examine and break down information into simpler parts and find evidence to support generalisations.	Dissect, Examine, Infer, Compare, Contrast
Synthesis	Compile information in a different way or propose alternative solutions.	Compose, Construct, Create, Design, Develop, Theorise, Elaborate, Formulate
Evaluation	Present and defend opinions by making judgements about the value of ideas.	Compare, Justify, Prove, Disprove, Deduct

University students are expected to develop analytical thinking mind. Developing analytical thinkers is central to the mission of all educational institutions. Therefore curriculum content, structure, and sequence at all grade levels have to support analytical thinking development. Many researchers, educators and related organizations include analytical/critical thinking as a core competency when evaluating general learning outcomes of college students. Many papers investigate critical and analytical thinking in higher education [3, 8, 9, 12, 16, 25].

In [24] the authors reviewed seven frameworks concerning general education competencies deemed important for higher education and/or workforce: (a) the Assessment and Teaching of 21st Century Skills, (b) Lumina Foundation's Degree Qualifications Profile, (c) the Employment and Training Administration Industry Competency Model Clearinghouse, (d) European Higher Education Area Competencies (Bologna Process), (e) Framework for Higher Education Qualifications, (f) Framework for Learning and Development Outcomes, and (g) AAC&U's Liberal Education and America's Promise. As the definitions in various frameworks overlap, we follow the Lumina Foundation publications regarding Degree Qualification Profile (DQP) that defines the following framework of students' learning outcomes in developing analytical thinking [2]:

a) "identifies and frames a problem or question in selected areas of study and distinguishes among elements of ideas, concepts, theories or practical approaches to the problem or question" (associate's level),

b) "differentiates and evaluates theories and approaches to selected complex problems within the chosen field of study and at least one other field" (bachelor's level), and

c) "disaggregates, reformulates and adapts principal ideas, techniques or methods at the forefront of the field of study in carrying out an essay or project"

The principal objective of this paper is to develop a questionnaire for the analytical thinking assessment of the current students in IT-related bachelor degree programs who we consider as Data Science potential students. Against this backdrop, some relevant tests such as existing assessments of analytical thinking, critical thinking, problem solving skills tests, etc. have been explored and analyzed in the next subsection.

2.2 Existing assessment tests of analytical/critical thinking

Popular form of critical thinking assessment is the California Critical Thinking Skills Test (CCTST). It targets the core critical thinking skills: a) analysis, b) interpretation, c) inference, d) evaluation, and e) explanation. Several scores are generated by the CCTST as follows: total score; inductive and deductive reasoning sub-scale scores; and sub-scale scores relating to the categories of analysis, inference, and evaluation [17]. The CCTST is usually used for learning outcomes assessment, performance funding,

program evaluation, professional development, training, and as an element in application, admissions, and personnel evaluation processes.

The Watson-Glaser Critical Thinking Appraisal (WGCTA) is another assessment tool designed to measure an individual's critical thinking skills. The critical thinking skills of inference, recognition of assumptions, deduction, interpretation, and evaluation of arguments are assessed by the WGCTA using just one score [13].

Other similar existing assessments of critical thinking are the Cornell Critical Thinking Tests, the Ennis-Weir Critical Thinking Essay Test, the New Jersey Test of Reasoning Skills, and the Ross Test of Higher Cognitive Processes, to name just a few [21]. The existing published tests vary widely in both purpose and item format, they tend to be general critical thinking assessments rather than subject-specific.

There are a number of challenges in assessing critical thinking skills and dispositions in students. Ennis believes that there are few critical thinking assessment tests that incorporate critical thinking as their primary concern [21]. Furthermore, he considers that critical thinking assessments fail to assess important, creative components of the thinking process like open mindedness, judging credibility of sources, conceiving of alternatives, formulating hypothesis and definitions, and developing plans for experiments. According to Ennis, this is primarily due to critical thinking assessments being written in multiple-choice questions versus short answer or essay.

In [16] the authors propose an operational definition for a next-generation critical thinking assessment. This framework consists of five dimensions, as follows: a) two analytical dimensions (i.e., evaluating evidence and its use; analyzing arguments), b) two synthetic dimensions, which assess students' abilities to understand implications and consequences and to produce their own arguments, and c) one dimension relevant to all of the analytical and synthetic dimensions—understanding causation and explanation.

We have been affected to a great extent by the existing assessment tests of analytical/critical thinking. In the next section a framework and the various stages of questionnaire development have been provided.

3 METHODOLOGY

The whole process of designing Analytical Thinking Skills Test (ATST) is depicted in Figure 1. We will consider all the steps separately as followed:

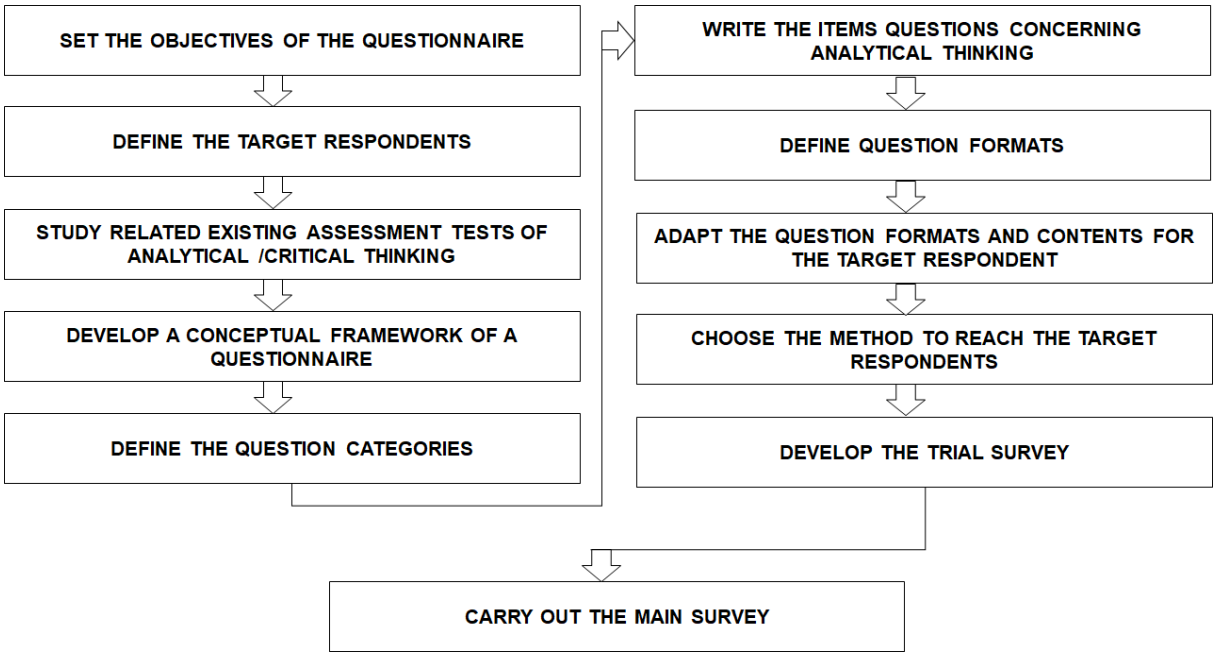

Figure 1. ATST development process.

3.1 Set the objective of the questionnaire

The aim of this paper is to develop a questionnaire to assess the entry competences assessment of Data Science potential students. The target respondents are provided various questions to assess their analytical skills to understand, to interpret and to solve different problems and tasks. The questions target assessment in four categories of analytical thinking:

1 AS: Checking ability to identify similarities, differences, progression in a sequences, contradictions;

2 AT: Answering by following the provided definition instead of applying intuitive well known attributes of given entity;

3 FO: Distinguishing between facts and opinions;

4 QR: Ability to compare quantities and to apply basic well known mathematical facts in every day situations.

3.2 Define the target respondents

The study includes a survey among undergraduate students who are potential candidates for the Data Science master program. Students from majors as Computer Science, Information Technologies, and Information Brokerage, who have passed training emphasizing different aspects of IT, were the primary target, but also students from other non-technical areas as Library Studies and Public Communications were approached.

3.3 Study related existing assessment tests of analytical/critical thinking

We have examined principles of analytical thinking, many relevant tests such as existing assessments of analytical thinking, critical thinking, problem solving skills tests, etc. It was described in details in section 2.

3.4 Develop a conceptual framework of the questionnaire

The test was designed to reveal the quantitative and qualitative aspects of the students 'learning progress in analytic thinking. Therefore, taking into account the above considerations (explored related existing assessment tests of analytical/critical thinking, the objective of the questionnaire and the target respondents), we need a framework, defining the dimensions of study. It is appropriate, at this stage to carry out a methodical examination of:

- Number of the items (to ensure the respondents not to become bored quickly - 20 items);
- Methods for evaluation of results obtained;
- Deadlines (for designing the questionnaire, data collecting and analyzing);
- Methods to reach respondents (paper or on-line);
- Possible formats of the survey (personal interview, quetstionnaire).

3.5 Define the question categories

Opening questions measure how students themselves rate their analytical thinking skills and dispositions.

The essential part of the questionnaire required a student to answer multiple choice questions indicated four categories of competences, five questions per each of the above categories: AS, AT, FO, and QR. Questions from different categories were randomly mixed.

3.6 Define the question formats

The constructed questions represent logical problems in three different formats: math questions, text assignment and figures pattern recognition. They are configured so the students can select multiple options from the list. We have also Likert-type scales questions which measure students' self-rating of their analytical thinking skills and dispositions.

3.7 Write the items questions concerning analytical thinking

The questions were randomly mixed among different categories and formats.

The following are examples of different categories:

Category 1. Which letter comes next in this series of letters OTTFFSS?

Category 2. A diamond is a circle. How many angles a diamond has?

Category 3. The sentence “Some people do not believe that modern communications will improve our way of living” expresses: a. Fact; b. Opinion.

Category 4. If $x=10^{-1}$, what is the value of $\left(x+\frac{1}{x}\right)\left(\frac{1}{x}\right)$?

3.8 Adapt the question format and content to the target respondents

Some items are adopted or adapted from existing tests, other are new, made especially for this questionnaire. We analyze items difficulty, reliability, etc. and adjust them to the target respondents and their likely level of analytical skills. Questions are written so that respondents understand them correctly, to ensure students’ active involvement, motivation and precise work.

3.9 Chose the method to reach respondents

The survey has been designed as an online questionnaire.

3.10 Develop the trial survey

As the main function of the pilot test is to detect flaws in the questionnaire in terms of content, grammar and format we ask our colleagues (university lecturers) and PhD students from Computer Science and Information Technologies departments to complete the ATST and provide their feedback.

3.11 Carry out the main survey

The survey was done in the Fall 2018. About 200 students on their senior year were approached by an on-line questionnaire.

4 CONCLUSIONS

From this study, ATST will be beneficial for students and teachers in assessing their analytical, creative and critical thinking, which meets the needs of further education.

The advantage of this approach is that individual and collective weaknesses will be identified. Then by appropriate planning of all disciplines syllabuses some specific and innovative topics, problem-solving activities, etc. can be included to address the areas of weakness and ensure analytical thinking development.

This should help to develop the reflection on how teachers succeed to train the right mix of skills and competencies. Students’ outcome assessment, which includes both demonstration of theoretical knowledge with close to real life practical problem solving, can help to discover proper didactic methods and techniques for analytic thinking skills development.

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