Bulletin of Education and Research
December 2015, Vol. 37, No. 2 pp. 09-25

Variants of Teaching First Course in Database Systems

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Abstract

In order to effectively conduct a course, the instructor should be clear about the course contents, methodology of teaching, and about the relevant literature, mainly, the textbooks. Furthermore, it is imperative to assign appropriate time to each topic so as to conduct the course efficaciously. To assist the Database course instructor in deciding these factors, some ground work has been done, which widely ranges from timely published computer science curricula by ACM and IEEE-CS to the articles published in journals and conferences. The major ingredients for this course are the course contents, and the methodology. Based on the course contents and a selected methodology two other factors are incorporated i.e. which textbooks are more suitable for each methodology, and how much time should be allocated to each topic in each methodology. To this end, we have conducted a survey of the top universities of the world, so as to accumulate relevant data that mainly comprises of the detailed course outlines. We have analyzed this collected data, and have also incorporated our own teaching experience, and as a principal contribution of this article we present a consolidated course content domain along with relevant learning outcomes, and different methodologies that can be used for teaching an elementary course in database systems.

***Key words*:** teaching/learning strategies; improving classroom teaching; pedagogical issues

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Introduction

A course on database management systems is considered an integral part of almost all variants of undergraduate degree programs pertaining to the domain of computer science. The importance of this course can be highlighted by the fact that it is considered as a core course in computing curricula, i.e. In order to complete the degree a student has to study this course successfully. In many disciplines, there exist, knowledge areas which are offered as a series of courses. As an example, there is a stream of computer programming courses, which includes an introductory course in computer programming, which is followed by more advanced courses in this domain. Furthermore, there are different possible methodologies to teach computer programming which include Object First Approach, Functional First Approach, or Imperative First Approach (Farooq et al. 2014). Similarly, a series of courses are taught in the area of database systems, and furthermore, different methodologies are used to teach these courses ("Computer Science Curricula 2013", Jun 2014) (Al-Shuaily et al. 2012)(Wagner et al. 2003) (Springsteel et al. 2000) (Howe et al. 2014).

In this article we focus on a first course in database management system, and discuss different methodologies which have been used to teach this course. To this end, we have incorporated IEEE/ACM curricula (Computer Science Curricula 2013), course outlines collected from different top universities of the world, and research articles. As a main contribution, we present the main ingredients of this course which include the course outline that covers the main topics to be covered, we also discuss the time allocation for each topic for different methodologies. Furthermore, we focus on the practical part of the course that may involve projects or practical assignments. Lastly, we incorporate the textbooks which have been widely used by the instructors.

The rest of the paper is organized in the following manner. In Section 2, literature survey is presented, which is followed by Section 3 where we introduce the major ingredients or content domain for an introductory course in database systems. Following the content domain, we propose various methodologies in Section 4. In Section 5, we presenta comprehensive discussion that mainly covers the suggested textbooks for each methodology; suggests the time distribution for each topic in the content domain for different teaching methodologies; and presents the suggested marks distribution for all proposed variants of teaching this course.

Literature Review

Time to time various people have addressed the need to improve the first course in database systems ("Computer Science Curricula 2013", Jun 2014) (Al-Shuaily et al. 2012)(Wagner et al. 2003) (Springsteel et al. 2000)(Howe et al. 2014). As a matter of fact, this improvement has been discussed at different times and in different dimensions, which include all-encompassing course contents and methodologies, along with specific areas like teaching SQL (Kleiner et al. 2013) (Dorling et al. 2012)(Al-Shuaily et al. 2012), teaching with the help of visual tools (Wang et al. 2009)(Wang et al. 2010), or using scientific data sets (Wagner et al. 2003). Therefore, we consider these research articles to gather different dimension of work conducted by the researchers to improve this course. As a second major source we have considered the recent ACM-IEEE curriculums (Cassel et al. 2008) (Shackelford et al. 2006) ("Computer Science Curricula 2013", Jun 2014) which are the essence of the discussion made by prominent educationists, researchers, and practitioners. We can obtain a general guideline for course contents from this curriculum.

Apart from this, we also incorporated the data that we have accumulated from different top universities of the world, which includes the course outlines, suggested textbooks, and lecture breakdown. This certainly gives a more realistic view of the in-practice teaching methodologies in world's famous universities.

Therefore, there are two major sources of input for this research. Firstly, we have considered the efforts made by different researchers and academicians to improve and evolve the course of database systems. Secondly, we have incorporated the data obtained from the top 100 universities of the world.

As mentioned above, to get a clear picture of what has been done so far regarding Database Course, research papers were gathered. They proved to be helpful to us as all of them mentioned some or the other points out of the four points mentioned above.

The discussion has mainly started back in the early 90s, where some people have discussed on what should be taught in this course (Metro et al. 1993), others (Bhogal et al. 2012) (Metro et al. 1993) (Guimaraes et al. 1999) have discussed the contents and methodology w.r.t. the general teaching considerations in the course of database in particular, and in the domain of computer science, in general (Rilett et al. 2013) (Schaeffer et al. 2011) (Strödter et al. 2012).

In (Adams et al. 2004) the authors mention different types of methodologies that can be adopted to teach a course in database systems. Here, the authors have discussed three different approaches to teach this course, which are theory based approach, project based approach, and a balanced approach. However, this paper lacks the solution to other problems e.g. discussion of course contents, time distribution for each topic, and recommended books.

M. A. Robbert and C. M. Ricardo (Robbert et al. 2003) solely specify the domain of the course content, and the percentage of it that was covered in years ranging 1999-2002, but have not mentioned anything about the rest of the considerations. In (Urban et al. 2001) the authors focus on the theory based approach for an introductory course and mention a course domain. Here the authors have distinguished between the advanced and introduction level topics. However, they have not discussed the inclusion of project and practice in the course.

A methodology adopting the practical approach has been described in (Ullman et al. 2003) where the authors suggest that each lecture should be followed by practice on tools. Similarly, in (Bhogal et al. 2012) the authors proposed a project based approach to conduct this course. In (Urban et al. 1997)(Wang et al. 2009)(Dietrich et al. 1996)(Wang et al. 2010) the authors propose a teaching methodology that is a mix of theory and practice, while suggesting the text books, grading schemes, and time distribution on different topics. Lastly, a very interesting and useful comparison on 13 top rated text books on database systems has been conducted by Megan Conklin and Lynn Heinrichs (Conklin et al. 2005).

Another very important source of information is the curricula developed and evolved by the ACM and IEEE. We have considered the curricula versions of 2005, 2008, and 2013 (Cassel et al. 2008)(Shackelford et al. 2006)("Computer Science Curricula 2013", Jun 2014), which give a good insight to the development and evolution of the courses taught in the area of Computer Science and Information Technology. These curricula not only provide detailed course contents but also highlight the major learning objectives for each topic covered.

In order to get a concrete guidance about what is actually being taught, and the strategies that are being practiced at various top institutions, we collected the data from the top 100 universities of the world. These top universities were taken from QS World University Rankings ("QS University Ranking", 2014). We tried to gather the course outlines from each university with the aim that it will help us in formulating the course domain, while at the same time the more detailed course outlines will help us in figuring out the time distribution of the topics. Similarly, a careful analysis of

the course outline would help us to categorize it to one of the teaching methodologies that the course outline is based on. Lastly, the information about the suggested text and reference books would help us to map the teaching methodologies to the famous text books, although, this mapping is widely based on the obtained statistics.

Unfortunately, all universities had not posted the course outlines on their websites. Out of these 100 we were able to acquire the outlines of 83 universities. The number of outlines gathered was ample for our research work. All these 83 outlines were then downloaded and reviewed thoroughly keeping all the research aspects in mind. While gathering these outlines our main focus revolved around the point that it should be an undergrad course whereby the discipline could either be Computer science, Information system or Information technology. Apart from this it was also ensured that we had latest course outlines.

Course Content Domain

To formulate a domain of the course content, the data of ACM Computing curriculum 2008 (Shackelford et al. 2006) and Computer Science curriculum 2013 (Cassel et al. 2008) have been considered as a premier source of information. Whereas, the articles covering the aspect of the content domain have been incorporated as supplementary sources of information. Lastly, the topics mentioned in the course outlines acquired from various universities have also been utilized.

In order to process the acquired data to obtain the final course domain for an introductory course in database systems, we used the following approach. The topics were shortlisted on the basis of their teaching frequency whereby the ones with highest frequency were included in our domain, and the ones with considerably very low percentages were excluded. For instance, the topic of *Query Cost Estimation* was found in a few outlines, but most of the outlines do not include this topic in the undergraduate introductory course. Therefore, we eliminate it from our course domain. This way, we managed to build a good quality content domain.

Table 1, shows the main topics of the content domain which should be covered in a first course in Database Systems. The topics are listed in such a way that one major topic covers one or more sub-topics. Furthermore, we have also listed the core learning objectives for each topic in the content domain by using the guidelines presented by ACM curricula (Computer Science Curricula 2013). This not only provides a complete course contents for an initial course for database management systems, but also helps matching the learning outcomes for each topic.

Table 1

Course Content Domain

Topics	Learning Objectives
Introduction to Database a. Database System b. DBMS Architecture c. Data Independence	Differentiation of files systems with Database Systems. Learning the components of a database system and their interconnection. Conceptual understanding and importance of data independence.
Data Models a. Conceptual Model b. E/R Model • E/R Design c. Extended E/R Features • Data abstraction d. Relational Model • Constraints - Key Constrains - Entity Integrity - Referential Integrity	To learn basic and advanced E/R modelling concepts and annotations. Learn to prepare a relational schema from a conceptual model. Understanding different levels of data integrity, and the importance of data integrity in maintaining the consistency of data.
Physical Data Design	To understand the underlying storage and indexing systems using different levels of granularity e.g. record level and file level etc.
Database Schema and Design	Learning the concept of metadata, data dictionary and constraints, and their application to a real problem.
Relational Algebra and Relational Calculus	Effective usage of relational algebra using mathematics set theory, and relational algebra operations especially designed for RDBMS namely *select, project, join, division.*
Functional Dependencies and Normalization a. Functional Dependency b. Normal Forms • 1NF, 2NF, 3NF, BCNF • Dependency Preservation • Lossless Joining	Learn to remove anomalies from design and defining good relations. Demonstrate the concept of functional dependency (FD) on relations, calculate minimal key from given FD, compute closure sets from given functional dependencies. For every decomposition ensure lossless joins and dependency preservation.
SQL a. DDL/constraints b. DML c. SQL Query - Basic and Complex d. Views e. Stored Procedure f. Triggers g. DB Authorization and Security	Learn how to query from given schema and apply strategies for optimal queries. Views, Stored Procedures, Triggers help implementing business logic at database level. Learn how to secure the database system by creating users with different roles and privileges.

Transactions a. Concurrency Control Technique • Isolation • Consistency b. Recovery • Atomicity • Durability	Basic concept of transaction managements, concurrency control and recovery. Demonstrate the effects of different isolation levels for concurrency control. Understand the usage of logs and schedules for backup and recovery.
Query Evaluation a. Query Processing b. Query Optimization	To learn the evaluation of query processing strategies so as to select the best one.
XML a. Schema b. XPath	Learning the idea of semi-structured data modelling using mark-up languages. Storage of data embedded in mark-up languages.
Indexing a. Unique/Non Unique Indexes b. B-Tree Index c. Bitmap Index	Learn the concepts of increasing the retrieval efficiency by minimizing the I/O calls, while involving different types of indexing data structures.

Teaching Methodologies

As discussed earlier the teaching methodologies to teach a first course in Database Systems have been presented in the literature. From the literature review and the analysis of the course outlines we have figured out different methodologies which have been used to teach this course. However, it is pertinent to mention here that none of the articles have discussed a methodology with all relevant details, which includes course contents, time and marks distribution, and relevant text books. The work in (Adams et al. 2004) (Ullman et al. 2003) (Al-Shuaily et al. 2012) (Metro et al. 1993) (Udoh et al. 2006) (Robbert et al. 2000) mentions different methodologies i.e. theory based, project or practice based approach. In this article, we not only define each methodology, but also highlight the considerations which should be used to decide as to which methodology should be used.

We map the outlines onto the methodologies, and have analyzed these outlines with the help of the topics covered and the time distribution for different topics, which certainly helps in identifying if the focus of the course is on theoretical aspects, or on practical aspects, or both are equally weighted. Furthermore, the outlines also provide auxiliary information about the marks distribution, which helps in identifying if the instructors are focusing on projects for the practical part, or they are relying on practice based assignments.

We identified the following four major methodologies:

i) Theory based approach
ii) Project based approach
iii) Practice based approach
iv) All encompassing/comprehensive (Theory + Pratice + Project) approach

Figure 1 depicts the percentages of universities following the particular methodology. Out of the top 83 universities 39% of universities are following Theory based approach, 26% are following all-encompassing approach that involves all three aspects, 20% universities are following Practice based approach, and 15% are following project based approach.

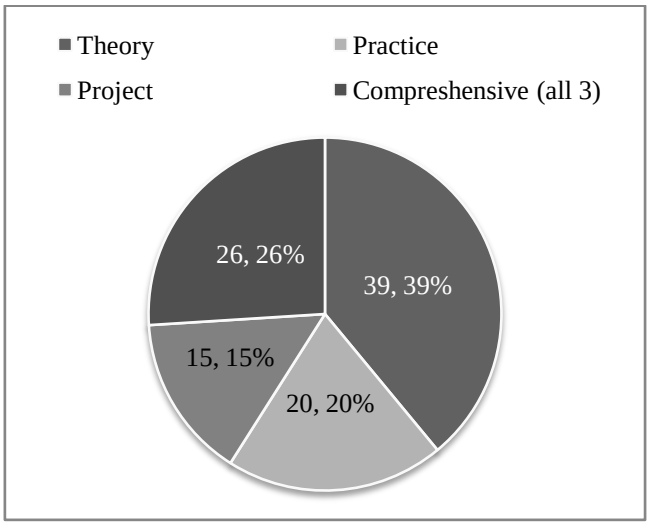

Figure 1: Percentages of selected universities following a methodology

Theory-based Approach

This methodology focuses particularly on theoretical concepts (Metro et al. 1993) (Abdullat et al. 2001). This approach does not involve any project or any practice lab sessions. Thus, a major portion of grading in this approach is given to the written exams in the form of mid-term and final exams. Most of the assignments are based on theory, but some of them may involve practical aspect. The main focus of this approach is to make students understand the core and fundamental theoretical foundation of Database Systems.

Project-based Approach

The aim of this methodology is to teach students the course of Database in a more practical way by giving them a major semester-long project (Adams et al. 2004) (Udoh et al. 2006). Along with course project minor assignments and quizzes will also be the part of the course. The idea behind this approach is that this project will help them in understanding and implementing the major concepts of Database systems. It will also help the students in learning the practical aspects of the course of Database systems. Moreover, it will also give the students a hands-on experience while using the tools used for database modelling (Raza et al. 2012) and development. Focusing on the cons of this approach one realizes that there will be no lab sessions, so the margin of routine practice is very low. Furthermore, the semester long project reduces the impact of home assignments given to students.

Practice-based Approach

The core purpose of this methodology is to provide the students with a lot of regular practice related to concepts of Database systems (Al-Shuaily et al. 2012) (Guimaraes et al. 1999) (Abdullat et al. 2001) (Kifer et al. 2005). Regular lab sessions should be held along with some non-theoretical assignments. These assignments may involve hands on experience on database modelling and development tools with the help of small assignments. Furthermore, a small project will be assigned which will help the instructor to evaluate what the students have gained from this course. Following this methodology requires to give students small assignments regularly.

All-encompassing Theory + Practice + Project Approach

This approach comprises of theoretical work along with regular practice based assignments, and a long project (Udoh et al. 2006) (Robbert et al. 2000). Students will learn the Database concepts during the lectures and those concepts will be implemented in the regular assignments, whereas the project will help them building an end to end application. Both theoretical and practical assignments will be included in the scheme. The practical assignments will be given for important practical topics e.g. practicing SQL, designing different schemas etc. They will certainly help the students to be able to complete their projects in a smooth way. This is also a comprehensive approach that includes lab sessions, along with proper blend of theory and project.

Discussion

In this subsection, we discuss the statistics, which support each methodology. To this end, we have discussed the number of universities which follow a given approach. Secondly, we also provide widely used marks distribution for different approaches. Furthermore, we discuss about the books which we found widely used by the followers of each methodology. Lastly, the time distribution for the topics in the content domain has been discussed for each methodology.

Time Distribution for Content Domain for each approach

In an attempt to suggest the time duration that how much time should be allocated to each topic under each methodology, the outlines of the universities mentioning their methodology were analyzed. Furthermore, we have also utilized our own teaching experience to refine the time distribution. Out of 83 outlines 20 outlines mentioned their time duration for the topics mentioned in them. Further, these 20 outlines were classified on the basis of the specified methodology, 14 outlines were separated out as a result of this. The time duration for each topic belonging to each methodology is proposed by carefully analyzing the course outlines, and by incorporating our own teaching experience. We have given a time distribution for a 3 credit hour course which involves 48 teaching hours in a semester. Table 2, shows the time duration (in hours) for each topic against each methodology. We have recommended to teach all topics in theory based approach, and in all-encompassing approach. Certainly, both these approaches cover same learning objectives. However, the suggested time allocation shows the theory based approach emphasizes more on learning the concepts like relational algebra, relational calculus, query processing and optimization, whereas the all-encompassing approach allocates lesser time and emphasis on these theoretical topics.

Apart from this, we suggest to drop some rather advanced and core theoretical topics including: query processing, optimization, and cost estimation in project based and practice based approaches. This way the learning objectives of these approaches are mainly focused on the hands on practices for the implementation of projects and assignments by the students. Thus, in these two approaches the idea is to increase the focus on the practice based topics including relational modelling using Computer Aided Software Engineering (CASE) tools, practicing basic SQL, and writing stored procedures and triggers. It also involves creating different indexes to improve the performance of the database systems.

The time-units allocation to each topic in Table 2 can serve as a guideline for the instructor to plan his lectures for the selected approach. Such guidelines can certainly ease the selection of methodology as well as course plan for new instructors of the course.

Recommended Text Books for each approach

Against each methodology, appropriate textbook has also been proposed. These books are proposed on the basis of their usage frequency in the selected universities and course content being followed by those universities. Some of the universities provided the information on their course textbook in their course outline. Also the gathered research papers (Conklin et al. 2005) listed some appropriate Database textbooks. These books are short listed on the basis of their usage frequency in those top universities. As mentioned earlier, the methodologies differ in course content, so the textbook allocation is an important factor.

We processed the course outlines which focus on theory based approach, and we found 10 different books being followed. Among these 14, 3 books were being followed with a high frequency rate. These books included, *Database Management Systems* by Raghu Ramakrishnan and Johannes Gehrke, 3rd edition, *Fundamentals of Database Systems* by Ramez Elmasri & Shamkant Navathe, 6th edition, and *Database Systems: The Complete Book* by Hector Garcia-Molina, Jeffrey D. Ullman, and Jennifer Widom 2nd edition. Any one of these books can be selected under Theory based approach.

There were 7 universities under the Project based approach, which mentioned their textbook being followed. All of these 7 books were different, therefore we recommend the book with highest usage frequency among all 100 universities, which may be followed under Project based approach, i.e. *Database Management Systems* by Raghu Ramakrishnan and Johannes Gehrke, 3rd edition.

Observing the Practice based approach, we came to a conclusion that only 5 universities mentioned their textbook for this approach. But focusing on the overall usage frequency, the book *Modern Database Management* by Jeffrey A. Hoffer, Ramesh Venkataraman and HeikkiTopi, 10th edition would prove to be a better choice in order to teach the students using the practice based approach.

Table 2
Time Distribution (in hours) for Different Approaches

Topics	Theory	Project	Practice	All encompassing
Introduction Database	2.5	1.5	1.75	2
Data Models				
E/R Model	3	4	3.5	3
Extended E/R Model	2	3	2.5	2
Relational Model				
Constraints	3	2.5	3	3.5
Relational Algebra/Relational Calculus	4	2.5	2	2.5
SQL				
DDL/constraints	0.75	1	0.5	0.75
SQL Query	3	3.5	4	4.5
Triggers	2	3	2.5	3
Views	1	2	2	0.75
DB Authorization and Security	0.75	2	1.5	1
XML	1.5	-	1.5	1
Physical Data Design	1.5	1.5	1.5	1
Query				
Query Processing	2.5	-	-	1.5
Query Optimization	2.5	-	-	1.5
Transactions	2.5	2	1.75	1.5
Concurrency Control	2	2.5	2.5	2
Recovery	2.5	2	2	2
Functional Dependency	3	3.5	4	3.5
Normal Forms	4	5	5	5
Indexing	1	2	1	1.5
Schema design	3	4.5	5.5	4.5

For the approach offering theory, practice, and project, 4 textbooks were found which were being followed. Highest usage frequency was of *Database Management Systems* by Raghu Ramakrishnan and Johannes Gehrke, 3rd edition, and the next most followed book was: *Database Systems: The Complete Book*. Both of these books provide the appropriate course contents that are suitable for this methodology.

Table 3 presents the most suitable books for each methodology.

Table 3
Recommended Text Books for different approaches

Methodology	Recommended Text Book(s)
Theory	*Database Management Systems* by Raghu Ramakrishnan and Johannes Gehrke, 3rd edition *Fundamentals of Database Systems* by RamezElmasri&ShamkantNavathe, 6th edition *Database Systems: The Complete Book* by Hector Garcia-Molina, Jeffrey D. Ullman, and Jennifer Widom 2nd edition
Project	Database Management Systems by Raghu Ramakrishnan & Johannes Gehrke, 3rd edition
Practice	*Modern Database Management* by Jeffrey A. Hoffer, Ramesh Venkataraman and HeikkiTopi, 10th edition
Theory + Practice + Project All Encompassing	*Database Management Systems* by Raghu Ramakrishnan and Johannes Gehrke, 3rd edition *Database Systems: The Complete Book*, or *Fundamentals of Database Systems*

Marks Distribution for each approach

Marks distribution and grading policy (Kleiner et al. 2013) (Heckert et al. 2006) are a very essential ingredient of designing a course for teaching. In the presence of various different variants of teaching a course, it becomes even more pertinent to devise a different marks distribution scheme for each methodology. In the same way, in our case, the grading policy is a prominent identifiers which helps distinguishing different methodologies. In general, marks are divided into four major parts i.e. course-project, lab-activities, mid-term and final examination, and the last part covers the assignments and quizzes taken in class. Based on the course outlines that we gathered from different universities, we have compiled a marks distribution for each methodology which is shown in Table 4. We present ranges of scores for different heads based on the data found in the course outlines, and by using our own teaching experience.

Table 4
Suggested Marks Distribution for each Methodology

Methodology	Project	Lab	Mid & Final	Assignments & Quizzes
Project	35-50	0	40-55	10
Practice	20-25	25	30-35	20
Theory	0	0	70	30
All encompassing	10-20	25	40-50	15

Conclusion

By extensive searching and analyzing the searched data, we were successfully able to achieve our goal and present the four main objectives that we listed in the first section. This paper has all the major ingredients which a database course instructor requires to formulate a work plan and devise a coherent and complete strategy for teaching database systems' course. Our paper has the capability to assist the instructor in every step taken forth while the deliverance of this course to his/her students. In future, the paper can be used to devise a program which takes some specifications from the user as input and gives a complete approach defining the content based on the learning outcomes, book and time distribution which meets the specifications of the user. In future this work can be extended to customize the teaching strategy while incorporating different degree programs, since this course is now being taught in several different undergraduate degree programs.

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