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Identifying Students' Misconceptions in Data Structures and Algorithms*

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Data Structures and Algorithms (DSA) is one of the core courses of Computer Science (CS) education. The course has several abstract concepts. In this study, misconceptions made by students relating to the Lists, also known as Linked Lists (LL), have been identified. The main and sub-problems were first identified, and then a three-tier multiple-choice conceptual understanding diagnostic test (or three-tier test) was prepared and administered to 291 students. The results were analysed and information about 14 misconceptions were obtained.

Keywords: misconceptions; data structures; three-tier diagnostic test; linked lists

1. INTRODUCTION

EACH BREAKTHROUGH achieved in CS nowadays directly or indirectly contributes to improvements in other disciplines. Sometimes, CS acts as a common ground, a meeting point for different disciplines and sometimes as a roof under which they are combined. CS is an indispensable partner for interdisciplinary studies and research. According to research, employment in CS will rise by 24% from 2008 to 2018, which is a lot more that the average growth in all other fields [1]. This fast growth and surprising advance also affects CS in terms of content and pedagogy. This situation requires reconsideration and review of academic curricula of introductory, intermediate and advanced levels of CS in hardware, software and all subfields [2].

In CS education, subjects are taught based on a curriculum starting from concepts followed by hardware and program codes. Hardware and software concepts in CS can be generalized as a) algorithmic b) programming and c) computing [2].

1.1 Concepts and misconceptions

Concepts are forms of knowledge that represent variable common properties of different objects and facts that are assigned a meaning in the human mind. Concepts facilitate creation by an individual of general ideas about his/her world based on that person's individual experience [3]. Misconception is generally defined as something a person knows and believes but does not match what is known to be scientifically correct [4].

As listed below, literature review showed that misconceptions result from following reasons:

- Mismatch between science concept and students' cognitive development levels, therefore, students are not able to understand abstract knowledge [5],
- Cognitive achievement and IQ status of students [5],
- Students learn their own concept from their experiences [6],
- Absenteeism of students [7],
- Informal learning which takes place outside of the formal classroom [8],
- Even preexisting knowledge affects misunderstanding of science concept because new concept could not match with old concept; therefore, theoretical knowledge and preexisting knowledge are significantly different in student mind [9].

Misconceptions eclipse and blur real concepts. Wrongly learned concepts at the beginning stage of education, which may sometimes be a result of the lack of knowledge or sometimes of misconceptions, lead to the wrong learning of concepts at subsequent stages and education failure. Moreover, they might be resistant and persistent to the extent of being uncorrectable, which makes them significantly dangerous.

Elimination of misconceptions is a process that needs to be run by teachers, the specialists in the field. In this process, a) students' misconceptions should be identified, b) an atmosphere of discussion should be created among students to make them face the misconceptions they have, c) by using a scientific approach and modelling, students should be assisted in restructuring and adopting information [10].

Studies and research on misconceptions are not new [11, 12] and studies conducted on a number of fields are available nowadays [13, 14]. It has been observed that interviews, open ended tests, multiple-choice tests, two-tier tests, three-tier tests and concept maps are used as methods in identifying students' misconceptions [10, 14–16].

Three-tier tests consist of three parts. In the first

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part, a student is presented with distracters and correct options. In the second part, the student is asked to provide a reason for his/her answer in the first part. In the third part, the student is asked whether or not he/she is confident about his/her answer in the two previous parts. Thus, the first stage consists of a true-false or multiple choice questions, the second consists of an open ended question and the third consists of two options (confident/not confident). If a student justifies his/her mistake by providing reasons and explains in a self-confident manner, it can be assumed that the student has a misconception. The difference of three-tier tests from other tests is their ability to indicate if the student's wrong answer is caused by a lack of scientific knowledge or conceptual error [16].

1.2 DSA and misconceptions

DSA are all technical and algorithmic characteristics of data types related to each other and to memory that define the data. As they run, compute programs generally use RAM in the first place in order to store their own codes and data they use. The most important issue in the development and design of a program is the identification of the data model that best suits the application in question and the stage of identifying the data structure. Software programs designed using DSA provide increased performance due to the efficient RAM use. It is possible to classify data structures as a) primitive (integer, float, Boolean, char) b) simple (array, string, structure, union, class) c) compound (linear (stack, queue, list) and non-linear (tree, graph)). DSA subjects cover a wide number of concepts.

DSA courses are available not only for CS students, but also for Computer Engineering and Electric Electronic Engineering students. Therefore, the course should not be considered as a course ensuring advancement in basic CS programming and problem solving skills. This is an important course that provides a focus on real-world problems, offering sound programming and data structure applications [17].

Research showed that misconception studies in CS are focused on the software field. This is because of the fact that programming education consists of interrelated syntactic, conceptual and strategic programming information [18] and that software contains more abstract concepts compared to hardware. The following are the example academic studies about misconception in software field: misconceptions of BASIC programming statements [19], misconceptions on efficiency of algorithms [20], student's misconceptions about programming techniques [21], a comparison of the misconceptions about the time-efficiency of algorithms [22], misconceptions about real-time databases [23], misconceptions in Computer Information Systems education [24] and identifying student misconceptions of programming [25]. As stated above most of misconception studies are concepts and misconceptions in programming language education which, in particular, affect algorithm efficiency among students starting the programming.

Concerning the DSA field, a number of studies have been conducted on the possibility of using concept maps and simulations for efficient learning of DSA concepts. Such as a pedagogical approach to conceptualizing data structures [26], observations on student misconceptions the build—heap algorithm [27], an approach to enhanced the learning of abstract data structures concepts by novice students [28], a simulation software for teaching concepts about the linked-list data structure [29–31] and an organizer for an online course in Data Structures and Algorithms with concept map technique [32]. However, students' misconceptions in LL of the DSA course are identified in this study.

1.3 Linked lists

The list or LL data model is based on the principle of consecutive storage in memory of data belonging to the same structure. LL is created through the use by elements called nodes [31]. As shown in the Fig. 1(a). node is a structure containing data and link member variables. Data can be a variable of any data type. However, link is a pointer variable defined as a node structure. The link information is the address of the next node. As shown in the Fig. 1(b), a list is a pointer variable defined by a node structure. If any nodes in the list, a list is void and the list variable has a 'NULL' value identified by '/' character. Otherwise, the address of the first node in the list is assigned to a list.

LL have four types as Singly-Linked Linear Lists (SLLL), Singly-Linked Circular Lists (SLCL), Doubly-Linked Linear Lists (DLLL) and Doubly-Linked Circular Lists (DLCL). As shown in Fig. 1(c). in the SLLL data model structure, the link of the last node in the list is NULL. In the SLCL, the link of the last node in the list points at the node in the beginning of the list in the Fig. 1(d). This research focused on SLLL.

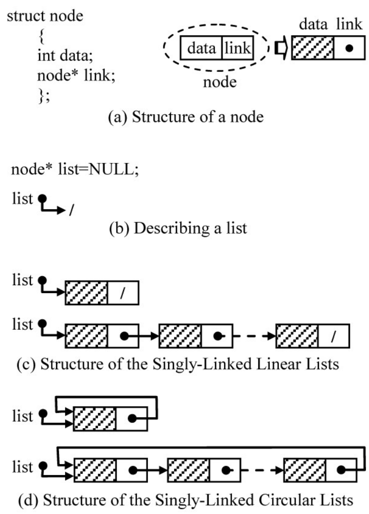


Fig. 1. (a) Structure of anode (b) Describing a list (c) Structure of the SLLL (d) Structure of the SLCL.

Table 1. Functions used in teaching the LL

#	Function titles	Function operation
1	void dumplist(node* list)	Prints nodes' address, data and link information of the list to screen
2	node* newnode()	Creates a new node
3	node* last(node* list)	Finds last node of the list
4	void addhead(node* node_, node*& list)	Appends node_ to head of the list
5	void concatenate(node*& l1, node* l2)	Appends l2 list to end of the list
6	node* cons(int data_)	Assigs data_ to data of a newnode
7	node* copy(node* list)	Creates copy of the list
8	node* locate(int data_, node* list)	Finds data_ in the list
9	bool member(node* node_, node* list)	Finds node_ in the list
10	node* cuthead(node*& list)	Cuts first node of the list
11	void free(node*& list)	Deletes the list
12	bool advance(node*& point)	Advances of point
13	bool deletenode(node* node_, node*& list)	Deletes node_ in the list

In this study, data models and algorithms of LL have been taught to the students with 13 functions indicated on the Table 1. These functions are basic and important operations over the lists.

Because the lists constitute the basis of other data structure subjects are one of most significant data structures in the programming. Misconceptions in the lists may lead to the mislearning of new concepts in the subsequent education process.

2. MISCONCEPTION RESEARCH

In order to find the answer to the main problem 'Do the students have misconceptions related to LL, a data model?' a three-tier multiple-choice conceptual understanding diagnostic test has been used as a measurement tool. The development, application and evaluation details of this measurement tool have been provided below.

2.1 Measurement tool development

The process of developing the measurement tool has been completed in four steps. Preliminary tests in this process have been administered to a 'test sample' of 32 students, which was different from the 'studied sample' consisting of 291 students, who have been the actual subject of application.

Step 1: Interviews were held with students in the test sample relating to the main problem of the study. Eight sub-problems presented in the Table 2 have been detected as a result of the interviews.

Step 2: The sub-problems in the Table 2 have been used to develop the open ended exam in the Table 3. The open ended exam questions prepared have been administered to the test sample. As a result of this application, concepts with high probability of misconceptions have been detected.

Step 3: Using the open ended exam results, a three-tier test consisting of 22 questions has been developed and administered to the test sample. Answers have been reviewed to see whether the questions prepared succeed or fail in detecting misconceptions. Expert opinion has been used to amend the root or answer options of some of the questions as well as to evaluate the suitability of some of the questions to the student level.

Step 4: The preparation of the conceptual understanding diagnostic test consisting of 24 three-tier multiple-choice questions, four examples of which have been presented in the Table 4 below, has completed and ready for administration to students in the studied sample group.

2.2 Administration of the test and obtainment of data

The research data have been obtained by administering the test to the studied sample with the following two constraints and four assumptions.

The constraints are:

1. This study is restricted to the 'lists' subject, which is a part of the 'Data Structures and Algorithms' course of the 3rd year of the Computer Systems Teaching program at the Faculty of Technical Education.

Table 2. Sub-problems of the study

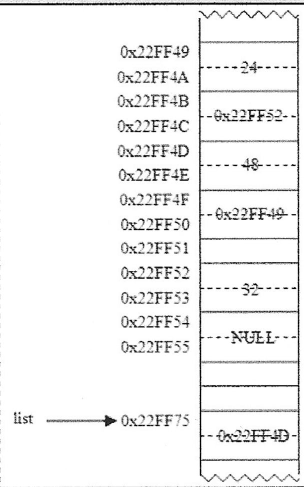
#	Sub-problem
1	Do they have misconceptions in the subject of the lists, which are one of the data structure models, on whether or not the nodes, depending on the way they are linked, reach all the data in the list?
2	Do the students have misconceptions in the structure of SLLL and SLCL nodes?
3	Do the students have misconceptions in defining the list structure?
4	Do the students have misconceptions in the list, which is a data structure model?
5	Do the students have misconceptions in the fact that the expression '&list' provides the address of the list in the memory?
6	Do the students have misconceptions in the fact that the expression 'list->link' indicates the address of the next node in the list?
7	Do the students have misconceptions in the fact that the expression 'list->data' indicates the data of the starting node of the list?
8	Do the students have misconceptions in the fact that the expression '*&list' indicates the address of the starting node of the list?

Table 3. Examples of questions in the open ended exam

#	Questions	
1	What is the difference between data and information?	
2	What is data structure?	
3	What is the difference between data model and data structure?	
4	What is SLLL? What structure do they have in the memory?	
5	What is the difference between LL and array?	
6	What is a node?	
7	What is the address operator (&) and pointer (*)? Please explain.	
8	What are SLLL and SLCL? Please explain the difference between them.	
9	Please explain the program code on the right line by line. In particular, analyze the function title.	void addhead(node* node_, node*& list) {node_->link=list; list=node_;}

10	Please explain the program code on the right line by line. In particular, analyze the function title.	void dumplist(node* list)
		{int i=1;
		while(list!=NULL)
		{cout<< 'List's '<<i++<<'.Node Address= '<<list
		<<' Data= '<<list->data
		<<' Link= '<<list->link<<endl;
		list=list->link;}
		}

Table 4. Samples of three-tier multiple-choice conceptual understanding diagnostic test questions

#	# Stage	Questions
1	1	Please reply by telling whether the following statement is true (T) or false (F). (...) Knowing the address of the first node is a must in order to reach all data in SLLL.
	2	Please provide the reason for the above answer:
	3	How sure were you in answering the above question? a) Sure b) Not sure
ATTENTION! Please answer questions 11 to 18 for SLLL using the figure provided on the right.		
11	1	What is the output of the cout<<list; command? a) 0x22FF75 b) 0x22FF4D c) 0x22FF40 d)24 e) 48
	2	Please provide the reason for the above answer:
	3	How sure were you in answering the above question? a) Sure b) Not sure

16	1	What is the output of the function on the right?
		a) 24–48–32 b) 32–48–24
		c) 48–24–32 d) 48–24–32
		e) 24–32–48
		
		void dumplist(node* list)
		{int i=1;
		while(list!=NULL)
		{cout<< list->data
		list=list->link;}
		}

	2	Please provide the reason for the above answer:
	3	How sure were you in answering the above question? a) Sure b) Not sure
19	1	Which of the following statements on the result of the cout<<list; command are correct? a) Indicates the memory address of the list variable. b) The list variable indicates the data of starting node. c) The list variable indicates the address of the starting node. d) The list variable indicates the address of the second node.
	2	Please provide the reason for the above answer:
	3	How sure were you in answering the above question? a) Sure b) Not sure

2. This study has been administered to a total of 291 students, 137 from Suleyman Demirel University, 40 from Sakarya University, 100 from Selcuk University and 14 from Mugla University.

Assumptions:

1. Some of the wrong answers the students have provided to the questions indicate misconceptions.
2. Item analysis and expert opinion have been sufficient and adequate in the preparation of test questions.
3. The questions are fully representative of the misconceptions tried to be identified.
4. The number of students in the studied sample is sufficient for a result that could be generalized.

2.3 Discussion of the results

As a result of the preliminary review of the test results, questions 6, 10 and 16 which had the least right answers and the answers of 46 students who have left the first three stages of the test questions blank have been excluded from the evaluation because of their negative effect on the test's conclusion.

The test results have undergone two different evaluations: First, 'a question performance rate' was based on the number of correct answers given by the students in all the three stages of the test; Second 'misconceptions rate' was uncovered from the answers provided by the students in all the three stages.

In the first evaluation, students correctly answering the first stage of questions were given 1 or 0 points if the answer is incorrect. During the second stage, the students were given 1 point if it could be concluded that the student provided the correct answer at stage one because of his/her knowledge of the subject, and 0 points if such a conclusion could not be made. Where the students scored 1 point in both stages one and two, and the answers were confirmed in stage three, the students were given 1 point for the third stage and were given 0 points if the answers were not confirmed. The students were assumed to have passed if scored 1 point in all the three stages of a question and failed if otherwise.

In the second evaluation, students marking the choice(s) with misconceptions in the first stage were given 1 point or 0 points if otherwise. In stage two, if it could be concluded that the choice marked in stage one containing misconception has actually been marked due to a committed misconception, the student was given 1 point for stage two or he/she was given 0 points if otherwise. Concerning the third stage, students that stated they were sure about their answers with misconceptions in stages one and two were given 1 point or they were given 0 points if otherwise. The total score of a question was 1 where a student had scored 1 point for each stage of the question. In this case, it could be concluded that the reason for the wrong answer was misconception. If a student scored 0 points at any stage of a question, the total score of that question was 0. In this case, it could be concluded that the reason for the wrong answer could be a student's lack of knowledge of that student or a scientific mistake.

The reliability of the test was separately calculated for each of the two evaluations using the reliability analysis of the Cronbach alpha coefficient. Cronbach alpha is a consistency coefficient with values in the range from 0 to 1. Depending on the performance, 0 means inconsistency and 1 corresponds to a 100% consistency. The Cronbach alpha value for the study has been found to be 0.80 ('highly reliable'). For misconception tests, Cronbach alpha coefficient of 0 meant that there were no misconceptions whereas 1 pointed at a 100% misconception. 0.49 was sufficient to indicate the presence of misconception. A lower reliability analysis result for misconception compared to the one for performance is a normal condition for misconception tests.

Table 5 presents 'the question performance rates' and 'misconceptions rate' based on all three stages according to answers provided in the 21 questions related to the 8 sub-problems.

First, as can be observed, 'the question performance rates' was based on providing correct answers decrease at further stages of the test. This indicates that the confidence of students in their answers is low, which indicates the possibility of a misconception.

Second, each of the sub-problems was researched using multiple questions. It was detected that some of the sub-problems accommodate multiple misconceptions. In conclusion, 14 misconceptions were identified. These misconceptions greatly affect student performance according to 'misconceptions rate'.

2.4 Analyzing the misconceptions

Misconceptions 5 and 6 have been detected to have the highest misconception rate. These are misconceptions in the node structure. The students have assumed the SLCL node structure to be DLLL and have confused the concepts Circular and Doubly. In the definition of the node structure, they have assumed the word 'node' to be a constant and separate word.

Misconceptions 2 and 3 indicate that the students have misconceptions in the possibility of reaching a node in the list from any node of that list relating to the lists Circular and Doubly. This is an important fallacy that requires attention.

Misconceptions 8 and 14 are misconceptions assuming that a list variable is always store the address of the first node of the list, in which the student has failed to consider that the list is variable.

Misconception 12 has been detected through a very wrong answer at the end of a question, asked relating to an application stating that a data

Table 5. Summary of the three-tier multiple-choice conceptual understanding diagnostic test

Sub-problem number	Number of the sub-problem related question	Question performance rates			Misconception number	Student replies containing misconceptions	Misconception rates		
		Stage one	Stage two	Stage three			Stage one	Stage two	Stage three
01	01	85.61	84.85	75.00	01	It is not required to know the address of the first node to reach all data in SLLL.	13.64	7.58	5.30
	02	56.06	47.73	38.64	02	It is required to know the address of the first node to reach all data in DLLL.	40.91	30.30	25.00
	03	63.64	59.09	48.48	03	It is required to know the address of the first node to reach all data in SLCL.	33.33	25.76	19.70
	08	75.00	71.21	62.88	04	The link of the last node in DLLL shows the address of the beginning.	24.24	16.67	14.39
02	04	51.52	50.76	49.24	05	Structure node definition in SLLL and SLCL is data and does not consist of one link only.	35.23	32.57	28.03
	07	75.76	74.24	72.73					
03	05	26.52	25.76	23.48	06	Only the "node" label is used as a struct name when defining a node for any list type.	42.42	39.39	33.33
	09	58.33	53.79	39.39					
04	19	53.03	50.00	42.42	07	A list variable stores data on the starting node.	24.24	21.96	14.39
	11	48.48	48.48	40.15	08	A list variable stores its own memory address.	28.40	24.61	24.96
	19	53.03	50.00	42.42					
	24	73.48	70.45	60.61	09	A list can only be linear.	7.58	6.82	3.79
05	12	58.33	57.58	47.73	10	The expression &list always shows the data of the starting node of the list.	17.80	16.66	14.01
	20	58.33	53.79	45.45					
06	14	46.97	43.94	34.09	11	The expression list->link indicates the address of the starting node.	21.97	18.68	11.36
	18	59.85	56.82	47.73					
	22	49.85	56.82	49.24					
07	15	32.58	31.06	25.76	12	The expression list->data is the address indicated by a list variable.	31.06	28	21.96
	15	32.58	31.06	25.76	13	The expression list->data indicates the value inside a list variable, which is the "null" value.	8.67	7.56	4.92
	23	78.79	73.48	62.12					
08	13	40.91	37.12	26.52	14	The expression *&list indicates the value of the starting node of the list.	34.59	27.52	20.20
	17	31.06	26.52	21.21					
	21	48.48	45.45	31.82					

variable is store an address. Analyzing the explanations provided to the answers, this condition indicates that the information on 'NULL' has not been comprehended correctly and that 'NULL' is perceived to be a data.

Misconceptions 7, 10 and 11 indicate that some students commit a fallacy by perceiving the dynamic structure of the list and link variables as static.

Misconception 4 has been committed as a result of perceiving DLLL as SLCL.

Misconceptions 1, 9 and 13 indicate that some of the students, even though at lower rates, may commit fallacy on the basic concepts of the lists subject by wrongly believing that a list has 4 types of structures, that data is defined as a pointer type and that in order to reach all data in SLLL, it is required to reach the first node of the list.

3. CONCLUSIONS

The purpose of this study is to identify student's misconceptions in the linked lists and to suggest how to overcome with these misconceptions. A four-step process and a three-tier multiple-choice conceptual understanding diagnostic test were used to get these objectives. At the end of the study 14 misconceptions were identified.

These misconceptions can be summarized in three main groups.

- misconceptions in node structure of the circular lists and the doubly lists
- misconceptions in the basic differences of the list types
- misconceptions in the uses of a list, a link, a data variables and 'NULL' value

These misconceptions may negatively impact the student's performance and efficiency of the lesson. Because overcoming these misconceptions which greatly affect performance. Struggle against misconceptions requires special educational effort. For correct on misconceptions, abstract concepts could be addressed with concrete examples. Teachers may prevent misconceptions by explaining concepts using different methods.

For example, new examples such as using course material and tools (simulation & animation software) can be provided while focusing on the misconceptions. Thus, the simple correction of the misconception may contribute future courses. It is important to share these findings among the teaching staff to struggle against the misconceptions.

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