Recognition, Reconstruction and Fault Identification Problems in Boolean Concepts Learning

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Abstract - **This study focuses on the cognitive complexity of Boolean concepts and the ability of the complexity measure to predict students' difficulties in problem solving. The study focused on three different measures of cognitive complexity. Based on these complexity measures, difficulties in solving problems were examined, such as recognition, reconstruction, and faults identification in digital systems. The relationship between a symmetry property of a Boolean concept and the different complexity measures presented.**

Keywords—Boolean Concepts, Recognition, Reconstruction, Faults, Digital systems

I. ITRODUCTION

Boolean concepts are given a great deal of attention in Engineering studies in general and Software Engineering and Electronic Engineering studies in particular. Bachelors of engineering students are exposed to and acquire an understanding of Boolean concepts in the second semester Digital Systems course during their first year. Digital Systems are based on Boolean algebra as its fundamental mathematical background. A large number of mechanical and electronic systems naturally lend themselves to Boolean representation [1].

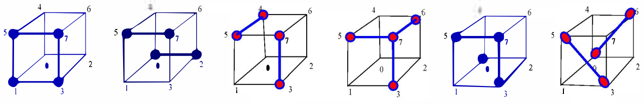
Different models are used for different types of content; the multitude of models creates a perceptual difficulty and complexity in understanding the Boolean concept when a transition is made from one content domain to another.

The standard approach in teaching a Combinatory Digital Systems course is by representing the problem using Truth tables and minimizing using Karnaugh maps. Understanding Boolean concepts has a huge influence on the students' cognitive and conceptual development. Acquiring Boolean concepts, representing them and using the concepts are the foundation for more advanced courses such as Digital Electronics, DSP-Digital Signal Processing, and so forth. Boolean concepts are the foundation for logical thinking, which the students use to cope with solving problems as part of their academic studies and later as engineers in the advanced technological world. This coping creates a fair amount of complexity from both a human and technological aspect. Human complexity is a cognition discipline expressed in cognitive development in learning and problem solving processes. It receives a great attention in psychology studies. From the technological point of view, complexity is determined according to Occam's razor. This principle states that no more entities than is necessary should be used; when there are different explanations for the same phenomenon, the simplest one with the smallest number of concepts should be chosen. The principle is used as a guideline in the information doctrine regarding the minimal length of a message. Complexity is determined according to the resources required to create a specific object. In Computer Science, the complexity of a string of characters is often measured by so-called Kolmogorov complexity, which is the length of a minimal computer program whose output is the string [2]. Designing of simple microprocessors (for example, RISC processors) capable to perform the minimal set of simple instructions is based on the Kolmogorov principles [3, 4]. The hardware complexity is traditionally measured by a number two-input logic gates implementing the corresponding specification. "Logic gates" are the basic units through which each digital device can be realized.

Our study is focused on three measures of cognitive complexity: Minimal Description (MD), Structural Complexity (SC) and Mental Model (MM). With respect to these complexity measures, difficulties in solving problems were examined, such as recognition, reconstruction, and faults in digital systems. In addition, the relationship between a symmetry property of a Boolean concept and the various complexity measures was examined.

A. Cognitive Complexity of Boolean Concepts

An important aspect of concept learning theory is the ability to predict the level of difficulty in learning different types of concepts. In this respect, the study of Boolean concepts, obviously, is an important topic of Engineering Education. Boolean concepts can be represented by Boolean expressions comprising basic logic operations: negation, disjunction ("or"), and conjunction ("and"). These types of Boolean concepts have been studied extensively by [5] SHJ. The SHJ studies are focused on Boolean concepts of three binary variables, where the concept is equal to "1" for 4 out of 8 possible combinations and "0" for the remaining 4 combinations.



Type $1_{3[4]}$ Type $2_{3[4]}$ Type $3_{3[4]}$ Type $4_{3[4]}$ Type $5_{3[4]}$ Type $6_{3[4]}$

Fig. 1: SHJ category types

Since some of such 70 possible Boolean concepts are congruent, they can be categorized as the same type into six subcategories. The six subcategories with structural equivalence can be described in a geometrical representation using cubes Fig. 1. Concept subcategories with structural equivalence belong to the same category and are defined as a Type. The study results pertaining to the six types of concepts presented in Fig. 1 show that the concepts belonging to Type 1 are the simplest and the subgroup of concepts belonging to Type 6 are the most difficult, according to the following order: Type 1<Type2<(Type3,Type4,Type5)<Type6. The results of this study are highly influential since SHJ proposed two informal hypotheses, the first being that the number of literals in the minimal expression predicts the concept's level of difficulty. The second hypothesis is that ranking the difficulty among the concepts in each type depends on the number of binary variables in the concept. The concept subcategory in Type 1 has one variable, the subcategory concept in Type 2 has only 2 variables, and concept subcategories in Types 2 to 6 contain three variables. Feldman [6], based on the conclusions from the SHJ study, defined a quantitative relationship between the level of difficulty of learning Boolean concepts and the concept's Boolean complexity. Assuming that D is the number of binary features and P is the number of combinations out of all the combinations in which the Boolean concept receives "1" Sum Of Products (SOP), D[P] indicates the family of Boolean concepts with D variables and P combinations where the concept receives "1". For example: the concepts that were examined by SHJ were represented as 3[4], 3 binary variables and 4 combinations in which the concept receives "1". In his study, Feldman examined the 3[2], 3[3], 3[4], 4[2], 4[3] concept family. The complexity measure of a Boolean concept as defined by Feldman, is the number of literals in the minimal expression that represents the concept's complete SOP. According to Feldman's definition of the complexity of the concepts and using an heuristic minimization technique for the SHJ's classification model, the complexity measures in each category are: Type 1: 1, Type 2: 4, Type 3: 6, Type 4: 6, Type 5: 6, Type 6: 10. According to this complexity measure, it is possible to predict that concepts of Types 3, 4, 5 have the same complexity and is learned easily than Type 6 but is harder than Types 1 and 2. These complexity measures predict difficulties in learning Boolean concepts, as examined by SHJ. Since there are several techniques for reducing an expression to the minimum, Vigo [7] presented use of the Quine-McCluskey (QM) technique to obtain a correct MD. He showed that it is possible to minimize the expressions more than according to the Feldman's hypothesis.

The definition of the Boolean concept's complexity as a minimal number of literals in a minimal expression creates a number of problems. The first: because the complexity is defined as the number of literals in the minimal expression and the expressions can be minimized using several techniques, the unique complexity measure does not exist. For example: according to Feldman's heuristics, Types 3, 4, 5 have the same complexity. Contrary to Feldman, in a more correct minimal expression according to Vigo, concepts from Types 2 and 3 have the same complexity. The second problem: studies show that the Boolean concept "xor" is learned and acquired as a concept in human thought to the same degree or even easily than the Boolean concept "or" [8]. By using the "xor" operator, some of the Boolean expressions examined by Feldman and Vigo can be simplified significantly and therefore, the complexity as a number of literals in the minimal expression decreases. In light of the problems presented, Feldman and Vigo developed alternative approaches for measuring the Boolean complexity.

Feldman [9] has introduced a so-called spectral decomposition model. In this model, the complexity of a concept is driven by its decomposition into a set of underlying regularities. The basic idea is that learning from examples involves the extractions of patterns and regularities. The formal model describes how a pattern may be decomposed algebraically into a "spectrum" of component patterns, each of which has a simpler or more "atomic" regularity.

Vigo [10] developed an alternative approach for calculating the complexity measure of a Boolean concept, defined as a structural complexity. The approach is based on a Boolean derivative. The question that the approach is supposed to address is: What is it about the internal structure of Boolean concepts from any category that makes them harder to learn than concepts from a different category? For the purpose of quantitative measure of the structural complexity, the degree of categorical invariance must be calculated. Vigo's account of the invariance of concepts does not specify how individuals learn concepts. The approach is based on the assumption that cognitive processes could detect invariances by comparing a set of instances to the set yielded by the partial derivative of each variable. In general, SC approaches do not comprise a mental representation of concepts or processes where the concepts are acquired as part of the learning processes. In [11] proposed an alternative to above approaches a MM complexity approach. The MM approach presumes that the mind is not logical and also not a probability system but rather, in essence, it conducts simulations. The theory applies to inclusion thinking and it presumes that when people think, they are attempting to imagine the possibilities of the presumptions that they must address and they draw conclusions. Each of the combinations from all the possibilities that receive a "1" in the result is a MM. When people learn the concepts they can minimize mental models by deleting irrelevant variables that are functions to other variables. The number of models of the concept that are obtained after deleting the irrelevant variables predict the difficulty of learning the concept and define the complexity measure of the concept's degree of difficulty.

B. Recognition Problems

The recognition problems are modeled in the form of visual representation of various objects in a common pattern, with composition of thus represented objects in the pattern. Solving the recognition problem may thus be understood as recognizing a visually-represented Boolean concept, with further formulation of the concept. The recognition problems can be perceived as a parallel process [12], so the recognition problems are considered of a parallel type.

One of the important roles of human consciousness is to reveal patterns and find data sequences. Not all the patterns leave the same impression on people as a basis for identification and perhaps subsequently, identical patterns are not equally observed by different people.

C. *Reconstruction Problems*

The process of finding and reconstructing operating mechanisms in a given functional system of a digital electronic apparatus is defined as reconstructing (RE) [13]. RE is applied in a wide variety of fields: competition in manufacturing new products, from electronic components to cars, among competing companies without infringing upon the competing company's copyrights, replacing system components with refurbished or spare parts, solving problems and defects in a system RE can be referred to as a certain type of problem solving. RE problem means reconstructing a Boolean function implemented within a given "black box". Since such a RE is typically performed sequentially, step-by-step, this type of problem can be considered a sequential type [14].

D. *Fault Problems*

Each of us occasionally finds ourselves trying to diagnose a fault or failure in some sort of system. For example, why is the car not starting? Why is the food not tasty? Why is the remote control not responding? Diagnosing failures and faults is ubiquitous in the professional lives of engineers, doctors, etc. It is inseparable part of engineering practice, were failures diagnostics of systems is required. Diagnosing failures is a type of problem solving and it is one of the cognitive skills that is learned and studied in psychology, computer science and artificial intelligence. Prior research has investigated fault finding in network tasks. One research aim has been to automate the process by; for instance, devising automated systems that are capable of diagnosing faults in large-scale industrial systems, such as power plants [15]. A failure occurs in a circuit or system when there is a deviation from a specific defined behavior. A fault is a physical defect that may or may not cause a failure. Diagnosing failures is not a synthetic or analytic action and not studied in the field of complex digital systems. In digital circuits, a fault may be caused by a disconnection in the conductors though which the signal passes, a short in the reference potential or the source supplying the electrical voltage, a short or disruption between the signal processors. In general, the fault's effect is represented using a model that represents the change that the fault caused to the circuit signals. There are three fault models: Stuck-at fault, Bridging fault and Stuck-open fault. "Stuck-at fault", where "1" or "0" must be determined at one of the entrances of the digital system or at the exit of the system regardless of the change of signals. A "Stack-at-fault" can be caused by a disconnection or short to the reference potential or the source of the power voltage. A "Bridging fault" is caused by a short between two conductors in the digital system. A "Stuck-open fault" is caused by a disconnection between two terminals in the digital system.

Our paper deals with two main questions. The first: How the cognitive complexity of a Boolean concept affects on the success of solving problems of: recognition, reconstruction and fault identification? This question addresses the research hypothesis that states that there is a difference between the complexity of the Boolean concept and the complexity of the problem given in various representations for the same Boolean concept. Boolean complexity depends not only on the complexity measures but also on the type of problem described by the Boolean concept.

Second question: Is there a correspondence between the success in solving Recognition problems, Reconstruction problems and the Failures identification problems?

This question addresses the research hypothesis which states that Boolean complexity influences the success or lack thereof in the three types of problems: recognition problems, RE problems and detecting failures, although the effect does not have to be identical for the three types of problems.

II. EXPERIMENT

The experiment was conducted in three stages for 10 concepts, where each concept was described by means of a Boolean expression in Table 1. During the first stage, RE problems were examined using a black box that could be used to control the lighting of a bulb using three independent switches for eight concepts with three variables concepts number (CN 1-8, Table 1) and using four independent switches for two concepts with four variables (CN 9 and 10, Table 1). The participants were required to try the different switch combinations that light the bulb and describe the combinations that light the bulb for each of the 10 concepts using a Boolean expression. A maximum of 5 minutes was allocated for each of the 10 tasks. The tasks were presented as a simulation on a computer monitor and the time taken to complete each task was measured. Successful completion of the task was measured based on correct solving during the allotted time.

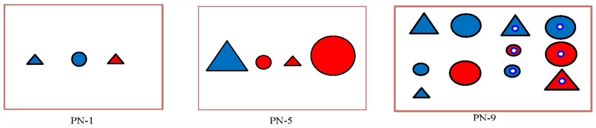

PN-1 PN-5 PN-9

Fig. 2: patterns for CN 1, 5 and 9

During the second stage, recognition problems were examined using a questionnaire with ten patterns, where each pattern represents one of the ten concepts examined, respectively, Fig. 2 presents patterns for CN 1, 5 and 9. The participants were asked to describe each of the patterns with as few literals as possible. A maximum of 60 minutes was allocated to completing the questionnaire for each of the ten patterns. The two stages of the experiment were conducted two days apart. Successful completion of the tasks solving both RE problems and the recognition questionnaire was measured based on correct solving in the allotted time.

CN	MD	MD (xor)	SC	MM
1	$\bar{b}(a+c)$ (3)	-	1.54	2
2	$\bar{a}c+b\bar{c}$ (4)	-	2.14	3
3	$\bar{a}\bar{b}+ab$ (4)	$\overline{a\oplus b}$ (2)	2.14	2
4	$a(b+c)+bc$ (5)	-	2.14	3
5	$(\bar{a}+\bar{b})\bar{c}+abc$ (6)	$\overline{c\oplus(ab)}$ (3)	2.34	3
6	$a+bc+\bar{b}\bar{c}$ (5)	$a+\overline{b\oplus c}$ (3)	2.79	3
7	$a(\bar{b}c+\bar{c}b)+\bar{a}(\bar{b}\bar{c}+bc)$ (10)	$\overline{a\oplus b\oplus c}$ (3)	4.00	4
8	$a(bc+\bar{c}\bar{b})+\bar{a}(\bar{b}c+b\bar{c})$ (10)	$a\oplus b\oplus c$ (3)	4.00	4
9	$a(b+c+d)+b(d+c)+cd$ (9)	-	4.48	6
10	$\bar{a}(\bar{b}+\bar{c}+\bar{d})+\bar{b}(\bar{d}+\bar{c})+\bar{c}\bar{d}$ (9)	-	4.48	6

Table 1: The 10 concepts were tested during the experiment and their descriptions according to MD, minimal descriptions using "xor"-MD (xor), (SC) and MM

All the solutions were examined compared to three complexity measures: complexity according to a MD of the expression (including using the "xor" operator), complexity according to SC and MM (see Table 1). An example for calculating structural complexity for concept 1 (CN-1 in Table 1):

$$F_{10}(a,b,c)=\bar{b}(a+c)=\sum(1,4,5)$$

$$\frac{\partial F_1}{\partial a}=F_1(a,b,c)\oplus F_1(\bar{a},b,c)=\sum(0,4)\Rightarrow F_{ap}=\overline{\frac{\partial F_1}{\partial a}}=\sum(1,2,3,5,6,7)$$

$$\frac{\partial F_1}{\partial b}=F_1(a,b,c)\oplus F_1(a,\bar{b},c)=\sum(1,3,4,5,6,7)\Rightarrow F_{bp}=\overline{\frac{\partial F_1}{\partial b}}=\sum(0,2)$$

$$\frac{\partial F_1}{\partial c}=F_1(a,b,c)\oplus F_1(a,b,\bar{c})=\sum(0,1)\Rightarrow F_{cp}=\overline{\frac{\partial F_1}{\partial c}}=\sum(2,3,4,5,6,7)$$

$$Im(a,b,c)=\left(\frac{|F_{10}|\cap|F_{ap}|}{|F_{10}|},\frac{|F_{10}|\cap|F_{ap}|}{|F_{10}|},\frac{|F_{10}|\cap|F_{ap}|}{|F_{10}|}\right)=$$

$$\left(\frac{\sum(1,4,5)\cap\sum(1,2,3,5,6,7)}{3},\frac{\sum(1,4,5)\cap\sum(0,2)}{3},\frac{\sum(1,4,5)\cap\sum(2,3,4,5,6,7)}{3}\right)=\left(\frac{2}{3},0,\frac{2}{3}\right)$$

$$SC=|F_0|\left[\left(\sum_{i=1}^{n}(Im_i)^2\right)^{\frac{1}{2}}+1\right]^{-1}=3\times\left[\left(\left(\frac{2}{3}\right)^2+0+\left(\frac{2}{3}\right)^2\right)^{\frac{1}{2}}+1\right]^{-1}=1.54$$

the number of combinations that concept receives "1"	MMs=3	Another option MMs=3
$\bar{a}\bar{b}c$ $\bar{a}b\bar{c}$ $\bar{a}bc$ $ab\bar{c}$	$\bar{a}b$ $\bar{a}\bar{b}c$ $ab\bar{c}$	$\bar{a}c$ $\bar{a}b\bar{c}$ $ab\bar{c}$

Table 2: example for calculating MM for CN-2

During the third stage, the students were tested with fault identification problems using 2 questionnaires where ten digital circuits realized with CMOS technology. Each of the circuits represents one of the ten concepts tested accordingly. Fig. 3 shows a circuit consistent with CN-4 in Table 1.

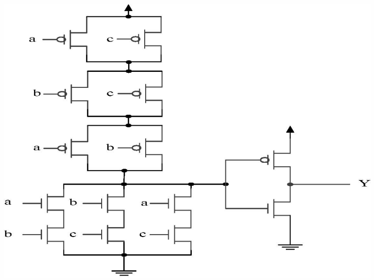


Fig. 3

In Part A, for each circuit the subjects were asked to find the Boolean function of the circuit. In Part B, they received a Boolean function that the circuit conducts as a result of a short type fault and were asked to discover the location of the fault and explain their answer. In Part C, they received a Boolean function that the circuit conducts as a result of a stuck-open type fault and were asked to discover the location of the fault and explain their answer. The questionnaire was divided into two. The first part had circuits corresponding to concepts 1, 3, 4, 6, 9 in Table 2 and the second questionnaire had circuits corresponding to concepts 2, 5, 7, 8, 10 in Table 1. The questionnaires were administered two days apart and 90 minutes were allotted to solve each questionnaire. The success of solving the problems was measured based on the correct solution during the allotted time. All the solutions were examined compared to three complexity measures: complexity according to a MD of the expression (including using the "xor" operator), SC and MM. Moreover, all the solutions in stage 3 were examined in comparison to the success or lack thereof in solving recognition and RE type problems.

III. METHOD

The research population includes 60 first year students studying for a Bachelor of Electrical Engineering degree at the college. All the students took the Logic Design course in the same study group and with the same lecturer in the second semester of year one. All the students finished the course successfully after the first exam with an average of 75 percent. At the end of the second semester of year one, the first and second stages of the study were conducted. Those same students took a Digital Electronic Circuits course in the first semester of their second year. The students completed the course successfully with an average of 78 percent. The Digital Systems and Digital Electronics courses were taught by different lecturers. All the students also took the Digital Electronics course with the same lecturer. An experimental environment using Lab View was developed on a computer monitor for "black box" RE problems. The monitor displayed a black box with switches and a bulb. The state of the switches could be changed by clicking on the appropriate key with the mouse. A change in the switch's state resulted in a color change from black to red and the written indication "off" (black) and "on" (red). According to the switch's state, the light bulb is either on or off. A lit bulb is green and has the word "on", and a bulb that is off is with the word "off". As soon as the participants reached the conclusion that they knew the appropriate logical function for the system of switches and the bulb, they were asked to write the states of the switches that light the bulb using a Boolean expression, written using an equation generator, and to press "finish". Time was measured from the moment the first switch in the box is pressed until the task was completed. A two-part questionnaire was developed for recognition problems. Time was measured from the commencement of solving the questionnaire to when each participant submitted his questionnaire. A 2-part questionnaire was developed for the fault problems. Each part contained five digital circuits; the circuits were realized for ten of the concepts examined in the study using CMOS technology. In each of the circuits, Stuck-open faults, bridging faults, and stuck-at faults were examined.

IV. RESULTS AND CONCLUSION

We examine the results and conclusions for the effect of the various complexity measures on the success or lack thereof in solving three types of problems: RE problems, Recognition problems, and Fault identification problems. We also examine the correspondence between them, and the research hypotheses were examined by answering the research questions. Additional aspects that we will examine are the effect of the "xor" operator on complexity, the "true principle" in RE problems, meaning whether the tendency is to focus on combinations that give "1" also for problems in which the number of combinations whose result is "0" is significantly less than the combinations that give "1".

Table 3 presents the results of the study of the three types of problems that were examined. The results of RE problems include success ratios, the average time required and the average of the tests that were completed by the subjects until they attained what they considered to be the correct solution. The results of recognition problems are presented in the Table 3 according to the success ratios in solving the problems. The success ratios in solving fault problems are presented in the Table 3 for the three types of faults that were examined. The results in the table are for each of the ten concepts that were examined in the study. In comparing the results of the RE problems with recognition problems, the subjects were more successful in solving RE problems than they were in solving recognition problems. Not a single participant that did not succeed in solving RE problems managed to solve recognition problems for the same concept. However, not all the participants that managed to solve RE problems were also successful in solving the recognition problems. For example, for CN-3, 27 participants managed to solve the RE problem, compared to 24 of them that also successfully solved the recognition problem. Difficulty in comprehending and learning a Boolean concept cannot be predicted based on Boolean complexity measures of the concept alone, but rather it also depends on the type of problem representing the concept. It can be concluded from the results that for problems where the information is absorbed concurrently, recognition problems are more difficult to learn than problems where the information is sequentially obtained, in this case RE problems. Therefore, the difficulty not only depends on the concept's complexity but also on the complexity of the manner in which the problem is presented.

The greater the complexity measure, the lower the success rates, except for CN-4, CN-9 and CN-10, which we will elaborate on later. It cannot be unequivocally concluded that the greater the complexity measure the lower the success rate for solving the concept. For concepts 1, 2, 3, 5, 6, 7 the success rates for solving both types of problems indeed decreases as the complexity measure increases, also according to the MD and SC measures. For CN-1, the complexity is the lowest and the success rate the highest. For CN-2 and 3, the complexity is slightly higher than CN-1 and the success rates are consequently smaller. The situation is the same for concepts 6, 5, and 7, respectively. The inverse relationship between the complexity and success rate also manifests in the average time required to solve the problems. As the complexity increases, the average time it takes to solve the problem increases accordingly. Complexity with minimal literals when the "xor" operator is involved is a measure that is the least predictive, relative to MD, SC and MM, of the subjective difficulty of successfully solving the problem. The majority of participants did not recognize the "xor" operator in three types of problems. Participants that grasped the "xor" concept as an operator to the same degree as the "or" and "and" concepts were more successful in solving the RE problems, recognition problems and their average time was substantially lower. It can be concluded from the results that if the "xor" operator is acquired as a concept to the same degree as the operators "or" and "and", the concepts' level of complexity decreases, the success rates increase, and the difficulty in solving the problem decreases. However, not everyone acquires the three concepts – "xor", "or" and "and" to the same degree. For most, the "xor" concept is more difficult to grasp than the other two concepts. Although the level of complexity of the concepts in problems 4, 9, 10 are higher relative to problems 1, 2, 3 the success rates for solving both types of problems recognition and RE is significantly higher and the average time needed to solve them is much lower. It can be hypothesized that the reason for this is that the concepts in problems 4, 9, 10 fulfill qualities of symmetric functions. Apparently, the MD and SC complexity measures are not sufficiently reliable in predicting the level of difficulty in solving the problems for symmetrical functions. Two RE problem solving strategies were observed. The first, adopted by 54 out of the 60 participants, was to attribute a logical value to one of the variables and conduct fewer checks of the combinations to a check times 2 consistently, building a MM for the combinations in which the transitions among them, a

CN	**RE problems**			**Recognition problems Accuracy (%)**	**Fault problems**		
	Accuracy (%)	av. time (sec)	av. tests		Accuracy (%) Stuck-open	Accuracy (%) Bridging	Accuracy (%) Stuck-at
1	100	94	6.83	95	100	90	85
2	80	120	10	75	90	75	80
3	95	105	7.33	80	80	75	75
4	100	53	5.5	80	90	100	90
5	80	140	9.33	50	80	70	70
6	75	152	9.5	40	90	80	90
7	50	214	19.15	30	60	50	60
8	60	198	16.5	30	50	40	40
9	100	123	12.16	80	90	80	90
10	90	137	13	60	90	75	80

Table 3: presents the results of the study of the three types of problems that were examined

change in one of the variables does not influence the state of the lit bulb. For CN-6, 9 and 10, only 10 out of 44 participants reached the solution for the states in which the bulb is not lit and managed to solve the problem, since the number of combinations in which the bulb is not lit is 4, versus 12 states in which the bulb is lit. They took the same approach with recognition problems in solving CN-6, 9 and 10, and succeeded. For the remaining participants, the "true principle" guided them in solving all the states, including the ones where it is more effective to examine the states in which the bulb is not lit, which were significantly lower than the number for states in which the bulb is lit. 6 students tended to use the strategy of covering all the possible states. They managed to reach the correct solution only for RE problems for concepts 1, 3, 4, and did not succeed in reaching the required solution for the other states.

With regards to the first research question and hypothesis: It could not be overwhelmingly concluded that the greater the complexity measure the lower the success in solving the problem. A distinction can be made between the complexity of the Boolean concept and the complexity of the problem. According to the results of the study, it can be stated that none of the complexity measures used in the study were able to predict the difficulty for the three types of problems that were examined, but it can be concluded that the MM complexity measure is better than the MD, and SC complexity measures in predicting the difficulty in solving RE problems. In contrast, SC is better at predicting the difficulty in solving recognition type problems and failure problems compared to the other complexity measures.

With regards to the second research question and hypothesis: It can be said that reconstruction problems are easier to solve than identification problems for a given Boolean concept. There were no subjects that succeeded in solving identification problems but not reconstruction problems. However, not all the subjects that succeeded in solving reconstruction problems also succeeded in solving identification problems for the same concept. Subjects that did not succeed in solving reconstruction problems also did not succeed in solving fault problems. In contrast, there were subjects that failed to solve identification problems but succeeded in solving fault problems, and vice versa. The results show that short between two terminals type fault problems are the most difficult to solve compared to the two types of disconnection problems and constraining a fixed logical value in one of the entrance signals.

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