2023-10-10

Expert-Novice Differences In Electrical Circuit Analysis Based On The Order Of Attention On Elements Using A Concurrent Think-Aloud Protocol

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EXPERT-NOVICE DIFFERENCES IN ELECTRICAL CIRCUIT ANALYSIS BASED ON THE ORDER OF ATTENTION ON ELEMENTS USING A CONCURRENT THINK-ALOUD PROTOCOL

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Conference Key Areas: *Engineering Skills and Competences, Lifelong Learning for a more sustainable world, Fostering Engineering Education Research*
Keywords: *Expert-Novice Differences, Problem-Solving, Electrical Engineering Circuits, Order of Attention*

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ABSTRACT

The difference between experts and novices during problem-solving has been established in several domains. However, in electrical engineering, studies are sparse. This study compares experts and novices in an introductory electrical engineering course. Four novices (students) and three experts (teachers) were made to solve eight circuit problems with a concurrent think-aloud protocol conducted remotely due to COVID restrictions in India at the time of the study. Experts predominantly followed the direction of the current showing a working-forward strategy. Conversely, Novices displayed a means-end approach by jumping to mathematical calculations more than anything else. In addition, the arrangement of complex circuits confused them as they tried to solve the circuits based on a superficial understanding of the problems. We discuss the results in the context of what is already known about expert-novice differences.

1 INTRODUCTION

Polya's problem-solving approach in 1945 (Ersoy 2016) comprises four fundamental stages: comprehension, formulation of a solution approach, implementation of strategies, and evaluation of the solution. Experts generally engage in all four aspects, while novices only use the latter stages. Research has revealed that individuals with well-organised domain-specific knowledge exhibit superior problem-solving abilities. In contrast, inexperienced individuals tend to employ surface-level frameworks and possess rudimentary domain knowledge. Experts possess a variety of problem-solving strategies and are capable of formulating precise plans before the actual execution of the solutions. They have a restricted repertoire of problem-solving strategies and rely heavily on explicit problem information while being susceptible to irrelevant information.

Psychologists and educational researchers have spent much time studying the characteristics of experts and novices in various fields, from science and engineering to chess and music. Previous studies in such disciplines have uncovered problem solvers' behaviour during problem-solving. One such study observed that experts emphasised all the significant stages of bacterial growth and the meiosis process in their illustrations of chromosome meiosis (Kindfield 1994). Experts in music composition employed a strategic approach that involved prior planning and a vast repertoire of procedures that flexibly considered various solutions and ultimately selected the most appropriate one (Colley et al. 1992). Novices rely on surface-level information when investigating genetic problems (Hardiman, Dufresne, and Mestre 1989), pay attention to structural aspects of energy and force problems, and prioritise visual appeal when engaging in geological structure sketching tasks (Jee et al. 2013). Experts also employ more heuristics and place a higher value on the availability of comprehensive information within design briefs (Björklund 2013; Dixon and Bucknor 2019).

Circuit diagrams represent an electrical circuit that uses symbols to represent electrical and electronic devices, such as resistors, capacitors, transistors, and switches. In electrical engineering courses, circuit diagram problems are often used to teach students about circuit analysis and design.

Some common types of circuit diagram problems include:

1. Finding the total resistance of a circuit: Given a circuit diagram with resistors in parallel or series, students may be asked to calculate the circuit's total resistance.
2. Calculating current and voltage: Students may be asked to calculate the current or voltage at different points in a circuit, given the circuit diagram and basic information about the circuit.
3. Circuit analysis: Students may be asked to analyse a circuit diagram to determine how different circuit components interact and how changing one circuit element affects the overall performance.
4. Circuit design: Students may be asked to design a circuit that meets certain specifications, such as a specific voltage or current output, using the knowledge they have gained from analysing circuit diagrams.

Overall, circuit diagram problems are an essential part of electrical engineering courses, as they help students develop a deep understanding of how electrical and electronic devices work and how they can be used to design complex systems. This study aims to examine the disparities between experts and novices in electrical engineering as it is a field and area from which we still need data. We seek to answer two interrelated research questions.

RQ1:- What discernible distinctions are between experts and novices in their approach to solving electrical circuit diagrams?

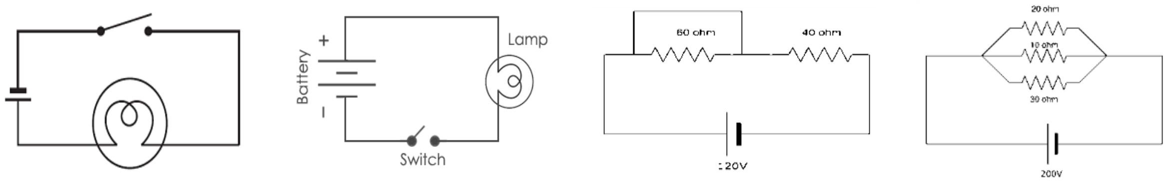
RQ2:- How do the findings of this study align with the information presented in the literature on expert-novice comparisons?

2 METHODOLOGY

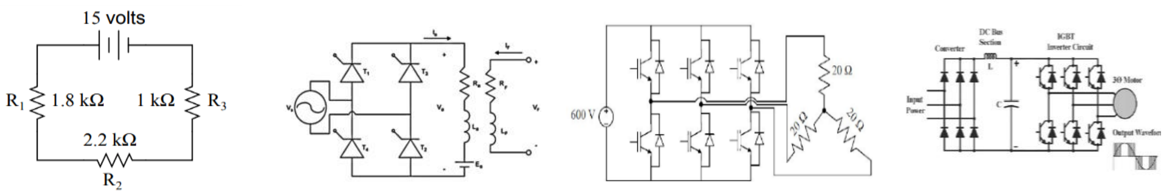
Three experts and four novices participated in this study. For this study, novices were students in their second year of an electrical engineering degree course at an engineering college in Maharashtra, India. The students successfully fulfilled the requirements of the "Basics of Electrical Engineering (BEE)" course in their first year. The experts had a sound understanding of the course material, were knowledgeable about the BEE course requirements, and held the academic rank of assistant professor with a master's degree in electrical engineering.

The initial plan was to conduct an eye-tracking study with the group. However, due to pandemic restrictions, we were forced to conduct a concurrent think-aloud protocol with remotely located participants. The study's participants were instructed over a video call to solve electrical circuits while concurrently verbalising their cognitive processes. A set of eight electrical circuit diagrams, each progressively more challenging than the last, were selected from the BEE course textbook followed in the college.

The first two circuits assessed fundamental knowledge of circuitry, as they feature uncomplicated components such as resistance, bulb, switch, and power source (Fig. 1.1 and 1.2). The next three circuits were interconnected through a combination of resistance in series and parallel configurations to satisfy Kirchoff's laws governing current and voltage (Fig. 1.3, 1.4, and 1.5). These circuits are moderately difficult. Finally, the last three circuits include advanced electronic components, such as diodes, transistors, and thyristors and were designed to investigate higher levels of concept mastery (Fig. 1.6 to 1.8).



1.1 *1.2* *1.3* *1.4*



1.5 *1.6* *1.7* *1.8*

Fig. 1. Basic Electrical Circuits from the electrical engineering curriculum

Following the presentation of diagrams to the participants, we documented their progress through remote observation on a video call. The subjects were asked to verbalise which components they looked at as they solved the problem. The researcher later processed this concurrent think-aloud data to create annotations on the circuit diagrams to mark their order of attention on the elements during the problem-solving process. Following the completion of problem-solving tasks, retrospective interviews were administered to participants to ascertain the rationales underlying their selection of components, paths, and strategies during the process of circuit solution. Each of the interviews above lasted approximately 10 to 15 minutes.

3 RESULTS

All eight circuits were analysed for the study. However, we will restrict our discussion to circuits in Fig. 1.1, 1.3, 1.5 and 1.6, as they were both representative and more interpretable. For the circuit shown in Fig 1.1, the novices directed their attention towards the switch (Sw), subsequently shifting their focus towards the bulb (Bu) and ultimately towards the source (Ba) (Fig. 2.(left)). The experts analysing the circuit focused on Ba initially, followed by Bu, and subsequently shifted their attention to Sw. However, their analysis did not conclude there, as they ultimately returned to the Ba to complete their solution (Fig. 2 (right)). The logic behind starting with the battery, as revealed in a later interview (excerpt below), was to discern the source of the current and the elements were visited in that order only.

Fig. 2: Novice's (left) and expert's (right) order of attention for circuit 1. The straight arrows indicate attention to elements such as switch, bulb and battery. The dotted line indicates attention to elements based on the direction of the current.

Expert-1 :

"...The search for current in the circuit began by examining the battery terminals to determine the direction of current flow. The direction of the current was then followed through each element of the circuit…."

Expert-2 :

"...When observing the current flow, it can be observed that it originates from the source and subsequently interacts with other electrical components before ultimately returning to the source to complete the circuit loop…."

The excerpts above provide valuable insights into experts' methodology in circuit analysis. These experts prioritise the direction of the current as a crucial factor in their approach to circuit problem-solving. Specifically, their initial step involves identifying the current's origin point and proceeding in that direction. This approach is further reinforced by the experts' adherence to the "Source-Load-Source" pattern,

Expert-3 :

"...I am not concerned more about the load but the source. Slight modulation in a circuit can lead to bigger changes in the application, so the source is more important to me…."

In contrast, novices showcased a generalised "Load to source" order of attention,

Novice-1 :

"...The determination of the response is contingent upon the load value. The load component is an integral aspect of any circuit, and the calculation of other components is dependent on the knowledge of the load value…."

The reasoning underlying the statement made by Novice-2 is:

"...The significance of load in circuit analysis lies in its ability to serve as a reference point for selecting the appropriate mathematical equation to solve the circuit…."

In circuits of greater complexity, such as Circuit 3 and Circuit 4 depicted in Fig. 3, the bulb is substituted with one or multiple resistors. Nevertheless, the observed pattern for such circuits remains consistent with simple circuits.

Fig. 3:- Novice's (left) and expert's (right) order of attention for circuit 3. The straight arrows indicate a focus on elements such as battery and resistances. The dotted line indicates attention to elements based on the direction of the current.

In Circuit 5, novice participants exhibited a random pattern as depicted in Fig. 4 (left) and (middle). Conversely, experts stuck to the pattern established in simple circuits, starting from the source and following the current. (Fig. 4 (right)).

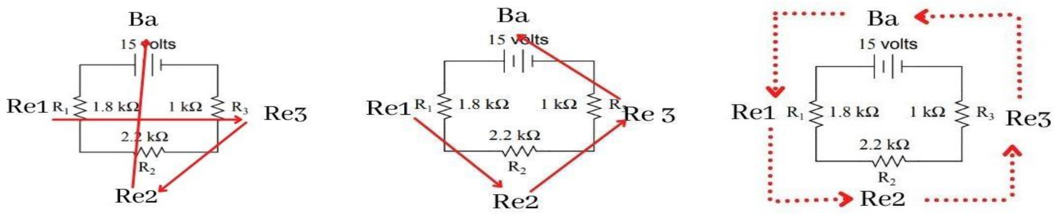


Fig 4.:- Novice's (left and middle) and expert's (right) order of attention for circuit 5. The straight arrows indicate a focus on elements such as battery and resistances. The dotted line indicates attention to elements based on the direction of the current.

Furthermore, the reasoning behind Fig. 4. (left) and (middle) was explicated by the novice as follows,

For the pattern in Fig. 4 (left), Novice 1 said :

"... I thought R1 and R3 are parallel to each other; that's why I saw them one after the other…".

However, for Fig. 4*(middle)'s* attention sequence, Novice 3 explicated :

“...All three resistances are in a series configuration. After looking at R1, I was looking for R2 so my natural instinct was R1, R2 and R3…”

In Circuit 6, the original battery was substituted with an alternating current (AC) source, and the basic linear loads, such as resistors and bulbs, were replaced with DC series motors (RLE represents the electrical equivalent circuit of a DC series motor). Additionally, a new current/voltage controller, such as a thyristor, is introduced. The novices showed order similar to easy and medium circuits. Experts, however, showed two distinct orders in this case.

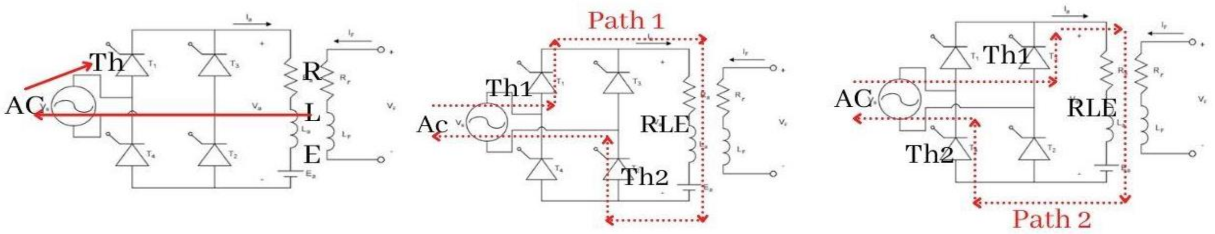


Fig. 5.:- Novice‘s (left) and expert‘s (middle and right) order of attention for circuit 6. The straight arrows focus on elements such as AC source, RLE load and Thyristors. The dotted line indicates attention to elements based on the direction of the current.

They have taken path 1 for positive half cycles, where voltage controller Thyristor 1 and Thyristor 2 are triggered (Fig.5 (middle)). Similarly, they have taken path 2 for negative half cycles, where controller thyristors T3 and T4 are triggered (Fig.5(right)).

4 DISCUSSION

We discovered two significant differences between experts and novices in this study. First, novices should have paid more attention to the source and concentrated more on the load side of the problem. In contrast, experts focussed on the direction of the current and visited the elements in that order, regardless of the complexity of the circuit. The focus on the load side of the problem by novices can be attributed to finding a solution to the question posed. This goal-oriented behaviour indicates the use of a means-end approach, wherein problem solvers concentrate on achieving the final goal of the problem by taking incremental steps and utilising various mathematical operators (Larkin et al. 1980; Sweller 1988). Some researchers have also referred to this behaviour as the "backward inference technique" (BIT), wherein novices identify what is being asked and work backwards until they find the information outlined in the problem (Rosengrant et al. 2009). In the context of a circuit, this was evident from the lack of attention to the current direction.

In contrast, experts predominantly base their approach on this fundamental concept in circuit diagrams, as reflected in their "source to load" order of attention. The direction of the current flow plays a crucial role in the solution process of experts, while novices tend to overlook this aspect. Experts displayed a working-forward method, in which they first infer critical intermediate solutions from the data provided to them, then delve into the principles required to solve the problem, and finally focus on the mathematical or analytical solution (Chi, Feltovich, and Glaser 1981; Larkin et al. 1980; Day 2002; Tabatabai and Shore 2005). This is often termed the "forward inference technique" (Rosengrant et al. 2009).

Second, novices' attention to elements was guided by superficial knowledge and/or problem representation, whereas core concepts guide experts. This difference is likely to give more variance in novices' order of attention than those of experts. For example, in Fig 4 (left), novices could make the incorrect supposition of R1 being parallel to R3 (superficial knowledge) or that R1, R2 and R3 need to be looked at in that order (superficial problem representation) in Fig 4 (right). This finding closely resembles the observations made by Fredette and Clement (1981) in their study. They discovered that students tend to depict the circuit elements as parallel in the circuit representation, even though they are in a series combination on the physical equivalent.

Conversely, experts follow the same pattern as they did for simpler circuits: follow the current, revealing an underlying dependence on core concepts and less reliance on external problem representation. Notably, the difference in expert order of attention for circuit 6, both path 1 and path 2, was not because of superficial knowledge or representational reasons but because of alternating current, again a key concept.

One way to reduce the observed expertise gap is to make the problem-solving of experts visible to novices. There may be more viable solutions for this purpose than explaining attention through concurrent think-aloud. However, eye-tracking technology may be used to illustrate an expert's way of solving a circuit problem. An eye movement modelling example or EMMEs, where novices look at the gaze patterns of experts that help them focus on the expert's problem-solving techniques, could be one way to do that. (Xie et al. 2021; Krebs, Schüler, and Scheiter 2019; Jarodzka et al. 2012)

5 LIMITATION

Despite the expected findings being congruent with literature from other domains, this study is limited because of its small sample size. Furthermore, looking at stimuli, comprehending them, and verbalising thoughts might have imposed an additional cognitive load on participants, and their thoughts may not reflect what was said.

This study was conducted during the pandemic using a concurrent think-aloud protocol, which is the strength of this study as it provides a roadmap for future studies in electrical engineering education that needs to be conducted remotely. However, this approach lacked precise control over the cognitive strategies employed by participants. To overcome this limitation, we propose to use an eye tracker of suitable frequency (>60 Hz) to record the order of attention of participants.

REFERENCES

Björklund, Tua A. 2013. 'Initial Mental Representations of Design Problems: Differences between Experts and Novices'. *Design Studies* 34 (2): 135–60. https://doi.org/10.1016/j.destud.2012.08.005.

Chi, Michelene T. H., Paul J. Feltovich, and Robert Glaser. 1981. 'Categorization and Representation of Physics Problems by Experts and Novices*'. *Cognitive Science* 5 (2): 121–52. https://doi.org/10.1207/s15516709cog0502_2.

Colley, Ann, Louise Banton, Julia Down, and Anthony Pither. 1992. 'An Expert-Novice Comparison in Musical Composition'. *Psychology of Music* 20 (2): 124–37. https://doi.org/10.1177/0305735692202003.

Day. 2002. 'What Is an Expert?' https://doi.org/10.1016/radi.2002.0369.

Dixon, Raymond A., and Jason Bucknor. 2019. 'A Comparison of the Types of Heuristics Used by Experts and Novices in Engineering Design Ideation'. *Journal of Technology Education* 30 (2): 39–59. https://doi.org/10.21061/jte.v30i2.a.3.

Ersoy, Esen. 2016. 'PROBLEM SOLVING AND ITS TEACHING IN MATHEMATICS' 6 (2): 9.

Fredette, Norman H., and John J. Clement. 1981. 'Student Misconceptions of an Electric Circuit: What Do They Mean?' *Journal of College Science Teaching* 10 (5): 280–85.

Hardiman, Pamela Thibodeau, Robert Dufresne, and Jose P. Mestre. 1989. 'The Relation between Problem Categorization and Problem Solving among Experts and Novices'. *Memory & Cognition* 17 (5): 627–38. https://doi.org/10.3758/BF03197085.

Jarodzka, Halszka, Thomas Balslev, Kenneth Holmqvist, Marcus Nyström, Katharina Scheiter, Peter Gerjets, and Berit Eika. 2012. 'Conveying Clinical Reasoning Based on Visual Observation via Eye-Movement Modelling Examples'. *Instructional Science* 40 (5): 813–27. https://doi.org/10.1007/s11251-012-9218-5.

Jee, Benjamin D., David H. Uttal, Dedre Gentner, Cathy Manduca, Thomas F. Shipley, and Bradley Sageman. 2013. 'Finding Faults: Analogical Comparison Supports Spatial Concept Learning in Geoscience'. *Cognitive Processing* 14 (2): 175–87. https://doi.org/10.1007/s10339-013-0551-7.

Kindfield, Ann C.H. 1994. 'Biology Diagrams: Tools to Think With'. *Journal of the Learning Sciences* 3 (1): 1–36. https://doi.org/10.1207/s15327809jls0301_1.

Krebs, Marie-Christin, Anne Schüler, and Katharina Scheiter. 2019. 'Just Follow My Eyes: The Influence of Model-Observer Similarity on Eye Movement Modeling Examples'. *Learning and Instruction* 61 (June): 126–37. https://doi.org/10.1016/j.learninstruc.2018.10.005.

Larkin, Jill, John McDermott, Dorothea P. Simon, and Herbert A. Simon. 1980. 'Expert and Novice Performance in Solving Physics Problems'. *Science* 208 (4450): 1335–42. https://doi.org/10.1126/science.208.4450.1335.

Rosengrant, David, Colin Thomson, Taha Mzoughi, Mel Sabella, Charles Henderson, and Chandralekha Singh. 2009. 'Comparing Experts and Novices in Solving Electrical Circuit Problems with the Help of Eye-Tracking'. In , 249–52. Ann Arbor (MI). https://doi.org/10.1063/1.3266728.

Sweller, John. 1988. 'Cognitive Load During Problem Solving: Effects on Learning'. *Cognitive Science* 12 (2): 257–85. https://doi.org/10.1207/s15516709cog1202_4.

Tabatabai, Diana, and Bruce M. Shore. 2005. 'How Experts and Novices Search the Web'. *Library & Information Science Research* 27 (2): 222–48. https://doi.org/10.1016/j.lisr.2005.01.005.

Xie, Heping, Tingting Zhao, Sue Deng, Ji Peng, Fuxing Wang, and Zongkui Zhou. 2021. 'Using Eye Movement Modelling Examples to Guide Visual Attention and Foster Cognitive Performance: A Meta-analysis'. *Journal of Computer Assisted Learning* 37 (4): 1194–1206. https://doi.org/10.1111/jcal.12568.