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Combining DoV framework and methodological preconceptions to improve student's electrical circuit solving strategies

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Abstract

Our research studies about student's prior knowledge acting as learning difficulties (referred to as preconceptions) in electricity courses at university level led us to define knowledge as the association of two elements: a model and a domain of validity (DoV). This statement is the core of the DoV framework. This framework reveals its powerfulness in the way it helps teachers to map students' cognitive structures, to identify their preconceptions as well as to derive effective teaching strategies. Quantitative experimentations we carry out indicate a lack of global circuit solving strategy among students. Especially, they highlight the fact that the difficulties encountered by those students in network analysis are not that much relying on the mastering of solving methods but on the method selection process. This lack of solving strategy prevents the students to grasp the domain of validity of the solving methods they master, so to associate the relevant methods with the suitable circuits. This paper depicts how the application of the DoV framework to this problem-solving process reveals to be a great tool to identify and tackle students' (methodological) preconceptions as well as to formalize, rationalize and simplify complex solving strategies making them easier to explain, teach and learn.

Keywords: *Preconception; domain of validity (DoV); electricity; network analysis; problem-solving process; solving strategy.*

1. Introduction

It is widely acknowledged that students come to courses with difficult-to-change prior knowledge (referred to as *preconceptions* in this paper) at both pre-university and university level, in particular in general physics education. Since several years, we are studying this phenomenon in circuit theory. Various experimentations led us to propose an original and formalized conceptual framework based on the concept of Domain of Validity: the DoV framework. This DoV framework reveals its usefulness and its powerfulness such as a frame of reference to better understand, identify and assess students' preconceptions or as a tool from which effective teaching strategies can be derived. The application of the DoV framework through experimentations (preposttest design, interviews, case study, etc.) with different research questions and objectives offered promising results (Sommeillier & Robert, 2017).

We go further in this paper by applying the DoV framework to complex problem-solving processes and by introducing the concept of *methodological preconception*. This new perspective is motivated by quantitative past examination and laboratory test analyses revealing that the difficulties encountered by the students are at least as much relying on the method selection process (i.e. the ability to select the most relevant and efficient method(s) to solve a circuit) as the mastering of solving methods themselves. This application of the DoV framework reveals to be a great tool to formalize, simplify and so to more effectively teach complex solving strategies. Several authors among have provided very interesting analyses about students' reasoning in circuit solving (Andre & Ding, 1991; Langlois & Viard, 2014; Viennot, 1979), but – according to us – with different perspectives and contexts.

Section 2 depicts briefly the seminal ideas of the DoV framework and how it integrates the concept of "preconception". Section 3 introduces the "methodological preconception" as an expression of a students' lack of global circuit solving strategy. Section 4 highlights the benefits of transposing the DoV framework to the network analysis process.

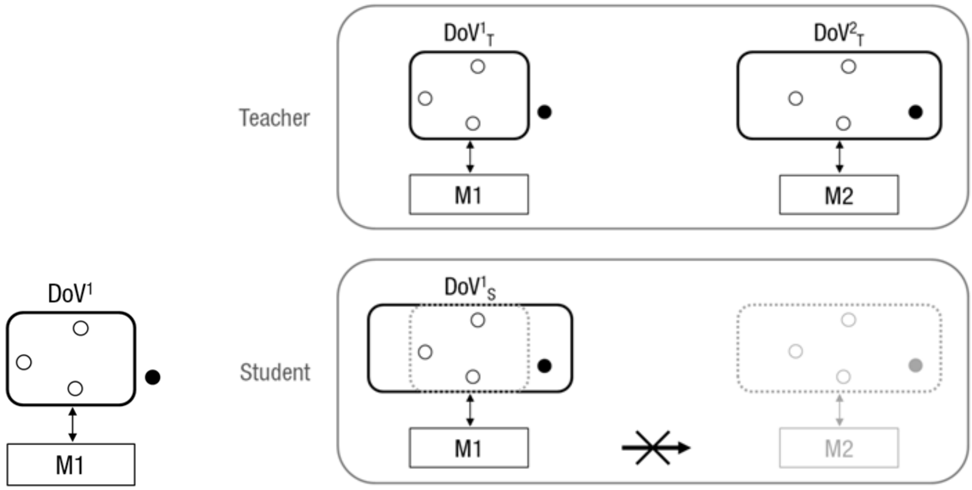
2. Domain of Validity framework

We study students' learning difficulties caused by prior knowledge in an engineering school. This approach prompted us to model the observed phenomena and derive an explicit teaching strategy to address these difficulties. We present in this section a conceptual framework we call the *DoV framework*, whose key concept is the *domain of validity* (or *DoV*) of a knowledge. This framework is based on two main assumptions (Subsections 2.1 and 2.2).

2.1. Knowledge is the association between a model and a DoV

We analyzed and summarized seminal ideas from existing constructs about prior knowledge (Sommeillier, Quinlan, & Robert, 2019): misconceptions, alternative conceptions, anchoring conceptions, phenomenological primitives (p-prims), threshold concepts, cognitive obstacles and conceptual changes (Posner, Strike *et al.*, 1982; Smith, diSessa *et al.*, 1994; Vosniadou, 2012) – to mention a few authors among many others. In most of those constructs, *knowledge* (or *conception* or *model*) is the central – if not sole – element of the cognitive structure. Discussion across the various constructs then tends to center on how valid that knowledge is in relation to expert views. We will refer to this these assumptions (knowledge is “atomic”, and its validity is the focus of debate) as the *monolithic view* of knowledge.

Instead, we hypothesize that knowledge consists of *two* connected elements: a *model* and a *domain of validity* (*DoV*). Both the model and the DoV are part of an individual’s cognitive structure, hence their *knowledge*. The DoV is the bounded area within which the *model* properly describes “real-life experiences”. Figure 1a illustrates this view: a piece of knowledge is the association of a model M1 and a domain of validity DoV^1 (represented by the rounded-corner box). The dots represent real-life experiences. Some of the dots are inside DoV^1 (white dots), while others are outside DoV^1 (black dot): M1 properly describes the three “white-dot” real-life experiences, but not the “black-dot” experience. These “experiences” include situations students may face in everyday life (observations, experiments, etc.) as well as situations created by the teacher (exercises, labs, problems, etc.).



(a) (b)

Figure 1. (a) Knowledge is a model associated with a domain of validity (DoV)
(b) Graphical formalization of the DoV framework

As a consequence of this hypothesis, there is no single “right” model surrounded by “false” models; models just coexist, having different DoVs. As a simple example, the model of the flat Earth is extremely useful and highly accurate when building a house, but disastrously inaccurate when launching a satellite. The coexistence of the classical mechanics (Newton) and the theory of relativity (Einstein) is another well-known illustration.

Introducing the DoV concept allows us to capture the fact that a model is sufficient in many circumstances, but not all circumstances. This situation is depicted at the top of Figure 1b (representing the teacher's cognitive structure) where two models M1 and M2 are both valid but in different DoVs. It leads us to abandon the idea that a conception is "right" or "wrong" and opens the door to multiple valid conceptions coexisting. According to us, explicit recognition of DoVs is today lacking in existing teaching strategies.

2.2. Preconception is the association between a model and an overgeneralized DoV

The second DoV framework hypothesis is that very nature of a preconception consists of an *overgeneralized DoV* (or *ODoV*): a domain of validity too wide relative to what the associated model can really represent. This simple hypothesis explains many phenomena related to prior knowledge. It also suggests that the typical blocking situation experienced in learning is due to the monolithic view of knowledge itself, held by the teacher and/or student.

Referring to the cognitive structure depicted on the top half of Figure 1b, this teacher has two models in mind, with different DoVs, both coexisting without contradiction. One black-dot experience (launching a satellite into orbit) is properly described by M2 (round Earth) but not by M1 (flat Earth). The bottom part of Figure 1b depicts the cognitive structure of students who possess a preconception related to M1: the students possess the same model M1 as the teacher but associated with an ODoV (including the black-dot experience covered by M2).

When the teacher presents the students with a black-dot experience for the first time (for which M2 is a better fit), students will use M1 according to their own cognitive structure (especially if the student is not conscious of a structural difference between this black-dot experience and the white-dot experiences). The student is confident in M1 because using it in the past has resulted in positive feedback from the teacher.

Our hypothesis also explains why, even when students understand M2, they may continue to apply M1: it is different to remember, understand, explain or even apply a model (which involves only the model itself) than it is to select an appropriate model when facing a real-life experience (which involves both the model and its DoV). Students could have learned and remembered a model M2 without having modified the DoV of a model M1.

3. Network analysis and methodological preconception

In the considered electricity course for 2nd year engineering students, the main learning outcome is to be able to solve electrical circuit problems, more specifically to perform efficient network analyses. Network analysis is the process of finding the voltages across, and the currents through, every (passive and linear) component in an electrical circuit. The circuits covered in this course include all circuit types from the most basic DC circuits with purely resistive components in steady state to the most complex AC circuits with reactive components and transient (Figure 3). When looking at solving any circuit, a number of methods and theories exist to assist and simplify the process. There are many different techniques for calculating these values, from electrical laws to mathematical tools.

We analyzed the answers provided by 796 students in past examinations (Sommeillier & Robert, 2017). This examination analysis indicates the difficulties encountered by the students are at least as much relying on the method selection process (i.e. the ability to select the most relevant and efficient method(s) to solve a circuit) as the mastering of solving methods themselves. In other words, when facing a new problem (or felt as if), students tend to improvise, which consists in ignoring what they fully master. This phenomenon is enhanced by the absence of a global solving strategy.

A laboratory test analysis we are undertaking leads to the same outcome. Figure 2 shows an example of those laboratory tests submitted to each student at the beginning of lab sessions. The aim of this question is basically to solve an AC circuit with a reactive component in steady state (Circuit type 7 in Table 1). The data analysis reveals that among the 156 students having passed this test, only 46 students (29%) answered a voltage amplitude of 5V which is the right answer. 76 students (so 49%) answered 7V and 34 (22%) didn't provide a numerical answer. This is due to the fact they – almost half of all 156 students – tried to solve it in the time domain ($3 + 4 = 7$ by simply adding the voltage amplitudes) instead of in the frequency domain ($\sqrt{3^2 + 4^2} = 5$ by using adding the corresponding phasors) as explicitly defined in all the course material and already practiced during exercise sessions. Thus, having no global solving strategy, students tend to apply a solving method outside of its relevant DoV.

[ELEC-H-2001] Electricity — Monday 5 November 2018
Laboratory Test n°1a — PM
LAST NAME : — First name :

Given this circuit with $e_S(t) = E.sin(\omega t + \phi)$, one measures a $3V$ voltage amplitude across the resistor R and a $4V$ voltage amplitude across the inductor L. What is the value of the voltage amplitude E of the power supply?

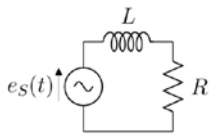


Figure 2. Laboratory test example with a reactive circuit with AC source in steady state (Circuit type 7 according to Table 1) – Translated from French

Regarding the DoV framework, this lack of strategy can be expressed in terms of *methodological preconceptions*. A methodological preconception is defined in the DoV framework identically to a classical preconception (Subsection 2.2): the association of a model with an overgeneralized DoV, with the particularity that the model referred to as a solving method and the DoV as a set of circuit types.

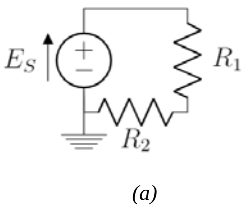
4. DoV framework applied to electrical circuit solving strategy

Being able to select the relevant methods for any circuit seen in this electricity course is not trivial. Indeed, the different circuits the students can face is infinite, the solving methods are numerous, and they can present slight differences in solving efficiency depending on the considered circuit types. Formalizing the method selection process and the steps required to solve any type of circuit illustrates the intricacy the students have to face.

By splitting the analysis in terms of DoVs on one hand and in terms of models on the other hand, the DoV framework reveals its powerfulness in its ability to formalize, simplify and categorize the constitutive elements of the global circuit solving strategy we are seeking for. First, focusing on the DoVs – and so on the different circuit types seen in network theory – it's worth to note that each of those circuits can be characterized by three binary parameters: the nature of the passive components (resistive or reactive), the type of power supply (DC or AC) and the fact that the circuit is permanently in steady state or that it presents a transient (absence or presence of a switch). Three parameters having each two possibilities give $2^3=8$ possible circuits. They are listed in Table 1. Figure 3 gives two basic examples of circuits of type 1 and type 8, while Figure 2 above presents a circuit of type 7.

Table 1. Eight type of electrical circuits depending on three criteria

Circuit type index	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Component type	Res.	Res.	Res.	Res.	Rea.	Rea.	Rea.	Rea.
Power supply	DC	DC	AC	AC	DC	DC	AC	AC
Switch presence	Yes	No	Yes	No	Yes	No	Yes	No



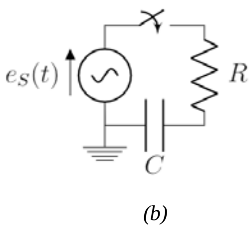


Figure 3. Examples of electrical circuits: (a) Circuit type 1 and (b) Circuit type 8

This circuit characterization allows to apply easily the DoV framework. Following the formalization depicted in Subsection 2.1, the idea is to identify for which circuit types each method is relevant or not. For instance, independently of the power supply type and of the presence or the absence of a switch, the “classical” solving method is suitable for circuits with purely resistive components (circuit types from 1 to 4). The fact this classical solving method is relevant for some circuit types and not for the others can be modelized by the graphical formalization of the DoV framework (Figure 1a). In this transposition (Figure 4a), the considered solving method is what we called the model in Subsection 2.1 and this model M1 is associated to the DoV in which its use is relevant: a set of circuit types 1 to 4 (i.e. a set of “real-life experiences”).

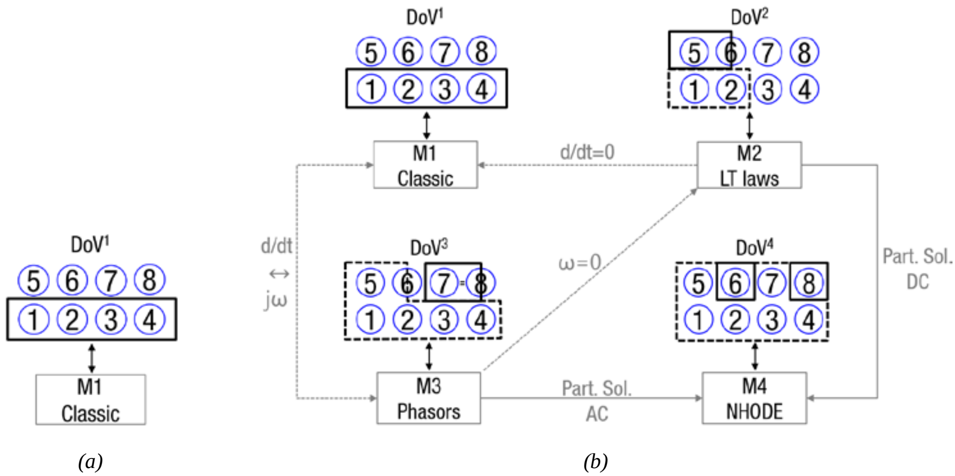


Figure 4. (a) First assumption of the DoV framework applied to one solving method.
(b) DoV framework as a tool to formalize and rationalize a global circuit solving strategy

In this framework, a methodological preconception consists in applying the model outside the appropriate DoV. For instance, referring to the example illustrated in Figure 2, applying the model M1 (classical solving method) to the real-life experience 7 (AC circuit with a reactive component in steady state) reveals the presence of this preconception. Processing similarly for each solving method allow us to radically simplify and rationalize the network analysis process which make it easier and more effective to teach. This study leads to a powerful formalization of a global circuit solving strategy illustrated in Figure 4b.

Combining the DoV framework and the methodological preconception to efficiently map students’ erroneous method selection in a formalization including only four models (solving methods) for eight circuit types. Confronting the DoVs appropriated to a model to the (potentially erroneous) DoV associated by the student to this model enables to easily identify the nature of the obstacles and to build a teaching situation helping to make the student aware of this obstacle and to overcome it efficiently. More generally, this formalized result widens the possibilities in rethinking the ways circuit theory and network analysis are taught from the identification of students' difficulties to the development of teaching strategies.

5. Conclusion

Network analysis is a fundamental learning outcome of any electricity course for which students encounter strong difficulties. Our experimentations indicate the difficulties encountered by the students are at least as much relying on the method selection process as the mastering of solving methods themselves. Applying the DoV framework to this problem-solving process enables to formalize and simplify this process. Combined with the methodological preconception, the DoV framework is a powerful tool to better identify students' difficulties in circuit solving and it offers a useful perspective to conceive efficient teaching strategies. This way to apply the DoV framework is not bounded to network analysis, to circuit theory or even to physics. More investigations have to be done to implement this approach in other fields and education levels. We are currently working on the development of a science-learning app in which a DoV-based teaching strategy is implemented in order to help students from all around the globe overcoming their preconceptions in different scientific fields. Finally, we recommend to any science teacher to adopt an approach combining the DoV framework and (methodological) preconceptions as a tool to better understand, evaluate, target and overcome students' learning difficulties.

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