Adapting Gowin's V Diagram to Computational Modelling and Simulation applied to Physics Education

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Abstract

Several research papers in physics education suggest that computational activities in modelling and simulation are potentially useful to facilitate meaningful learning in physics, provided that students engage themselves in these activities and critically think about them. Sometimes, excited with the possibilities offered by technological resources, we imagine that some representations "speak by themselves" in such a way that students' comprehension of physical phenomena will occur just by seeing them. However, to know how to use an instructional tool is at least as important as having it. In the case of computational modelling and simulation, for instance, it is not enough just to use them in instruction, it is necessary to make students think about what they are doing, about the physics involved in the models and simulations that they are dealing with. Thus, we decided to build an heuristic tool to help students in the task of creating and analyzing computational models useful to investigate the telling questions proposed regarding some physical phenomenon of interest. We created then what we call an **AVM** diagram which consists of an **A**daptation of Gowin's **V** diagram to computational **M**odelling and simulation.

AVM diagram

Among the many ways of using the computer in the teaching of science in general, and physics in particular, the computational activities of simulation and modelling stand out for potentially allowing students a better understanding of scientific models expliciting relationships among variables, the visualization of highly abstract elements, and their interaction with the content to be learned, among other things. These activities, as we see them, are distinguished from one another; basically, because of the access the student has to the mathematical or iconic model underlying its implementation. In a computational simulation representing a physics model, the student may add initial values to the variables, change parameters and, in a limited way, modify the relationships among the variables; however, he/she does not have autonomy to change the heart of the simulation (defined by a pre-established mathematical model), that is, to access the most basic constitutional elements. Student's interaction with the simulation has an eminently exploratory character. Computational modelling can also be thought in exploratory terms; in this case, the student receives a computational model ready and must explore it, but with the difference of having access to its basic features, even though, in some activities, he/she may not be asked to alter the basic structure of the model.

The exploratory activities, in general, are characterized by observation, analysis and interaction of the subject with previously built models so as to allow the perception and the understanding of possible existing relationships between mathematics, which underlies the model, and the physics phenomenon in question. In this kind of activity, the student is motivated to interact with the computational model, by answering questions presented as directed questions and "challenges". This interaction occurs through changes in the initial values and parameters of the model, using resources such as "scrolling bars" and "buttons" to facilitate the modifications. In the case of the exploratory activity of computational modelling, the student has access to the basic structure of the implemented model, being able to change it if he/she desires to do so.

Another possible way of working with computational modelling applied to teaching is the so-called expressive mode[1]. The activities developed in this mode can be characterized by the developing process of the model from its mathematical structure to the analysis of the results it generates.[2] In this kind of activity, questions aimed at the elaboration of models from certain phenomena of interest, about which qualitative as well as quantitative information on the system may be given, are presented. The student can interact completely with his/her model, redesigning it as many times as it seems necessary to validate the computational model and the production of results that may seem satisfactory to him/her.

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[1] Many times called "creation mode".

[2] In this category there are different forms of implementation of the computational model, for instance, inserting mathematical equations and/or building iconic diagrams in appropriate software, or using some programming language.

Based in the great success obtained through the usage of the V diagram, also known as Gowin's V (Gowin, 1981; Moreira & Buchweitz, 1993), in the analysis of the process of knowledge generation, and in order to extract knowledge documented in research papers, books, essays, etc., we decided to propose an **A**daptation of Gowin's **V** to Computational **Modelling** and Simulation (the AVM diagram), as presented in Araujo (2005). The V form of the diagram, originally proposed by Gowin, is not something fundamental. Other forms could be chosen, but we adopted, for the AVM diagram, the V form because it shows the interaction between the two indispensable domains to the development of a computational model guided to the teaching-learning process of physics: the theoretical domain, related to the conception of the computational model; and the methodological domain, associated to the implementation and/or exploration of this model.

In the center of the AVM diagram, there is the phenomenon of interest, which we desire to approach and the focus-questions that direct the analysis/design of the computational model. In the basis of the diagram, there are the problem-situations, which are descriptions of the situation/event under investigation to answer the focus-questions that contextualize the phenomenon of interest.

The left and right side of the AVM diagram can be visualized in detail in figure 1. The left side of the diagram concentrates on the theoretical aspects of the planning/analysis of the computational model. This side shows the *philosophy*, that is, the systems of beliefs underlying the problem-situation modelling process; the *theories*, *principles*, *theorems* and *laws* that guide the development of the model; the *idealizations* and *approximations* assumed, which determine the context of validity of the model; the internal *entities* of the system being modeled and the external agents that act upon it; the signs by which they are represented; the *variables* and *parameters* used to represent states and properties of the entities of the model; the mathematical or propositional *relationships* (a technical statement such as "the bigger this.. the smaller that");the *known results,* used for an initial validity of the model, which can be inferred from the theories, principles, theorems and laws assumed for the designing of the scientific model that we want to represent in the computer and which will also depend on the previous knowledge the designer has about the system represented. At last, we have the *predictions*, which are no less than initial attempts to answer the focus-questions before carrying out the model.

On the right side of the AVM diagram, corresponding to the methodological domain, there are: the *records*, that is, the data collected to try to answer the focus-questions; the *interactive elements*, related with the possibilities of altering parameters and variables during the execution time of the computational model; the *representations*, given by the model (graphics, table, etc.) and pertinent to the search for answers, obtained from the transformation of records; and the *modelling categorization*, according to the following classification concerning:

a) mode (*expressive*: when a model is built by the subject; or *exploratory*: when the subject just explores it);
b) kind (*qualitative*: linked to the modelling of linguistic constructions and textual productions; *semi-qualitative:* linked to the usage of causal diagrams, not involving numerical relationships; *quantitative*: bonded to mathematical models, involving numerical values and relationships as inequality and equations);
c) implementation: in the expressive mode, a description of the way in which the model was implemented in the computer (through the use of metaphors, programming language, insertion of equations similar to manuscript form, etc.) and the tool used (*PowerSim, Fortran, Modellus*, etc.) In the exploratory mode, an indication of whether it is an autonomous simulation, or it needs to be executed in some program must be expressed. The computational tool used to build the simulation also must be indicated whenever possible.

Still on the right side of the V, we have the *validation of the model* step, in which we compare the known results with the ones generated by the model. In case there is a disagreement between them, the model is considered unsatisfactory and must be modified until it comes to reproduce the known results. In this stage, the model is said to be validated. Then, we come to obtain the model assertions, that is, the answer (s) to the focus-question(s) that are reasonable interpretations of the records and representations supplied by the model, also allowing the evaluation of the predictions. At last, we have the *possible generalizations and expansions* of the model, which are the generalizations about the applicability of the structure of the model and how to expand it in a way to include variables and relationships not considered initially (change in idealizations and principles), broadening its context of validity.

It is important to emphasize that there is a permanent interaction between both sides of the AVM diagram in a way that everything that is done in the methodological side is guided by the components of the conceptual side in an attempt to develop/analyze the model and answer the focus-questions. This interaction mimetizes the recursivity intrinsic to the modelling process. We propose four applications of the AVM diagram to the teaching of computational modelling and to the exploration of computational simulations to the learning of specific contents.

1) Guided exploratory mode: in the AVM diagram, the phenomenon of interest, the focus-questions and the problem-situation are defined by the teacher and a computational simulation is presented. The reflexive elaboration of the V will serve as a guide to the exploration of the model so as to answer the focus-questions. Activities built this way may avoid that students distract themselves with details and end up not capturing essential aspects of the model focused by the teacher, especially when in too elaborate and "realistic" simulations.
2) Open exploratory mode: a computational simulation is presented and it is asked that, through the AVM diagram, the student explores the model in a reflexive manner, paying special attention to the formulation of the focus-questions. This mode may be especially useful for designing educational materials from the simulations created by others, which is interesting to the teacher, who can come to use the materials available in the web, for example, as well as to the students.
3) Expressive guided mode: in this case, the phenomenon of interest, the focus-questions and the problem-situation are previously supplied by the teacher, while the student elaborates the rest of the V and designs the corresponding computational model. This mode can be used when we desire the students to build a computational model about a specific content, taking in consideration focus-aspects defined by the teacher.
4) Open expressive mode: these are proposed activities in which the student must design a computational model from the reflexive elaboration of the AVM diagram, defining him/herself the focus-questions and the problem-situations which will guide his/her work. This way of using the AVM diagram may also guide the teacher in the building of his own models.

During the process of creation of the AVM diagram as an heuristic tool for the computational modelling and simulation applied to the teaching of physics, we considered the five non-hierarchical stages defined by Halloun (Halloun, 1996), the six stages defined by Santos & Ogborn (1992), the strategy for building models presented by Ferracioli & Camiletti (2002), the considerations on the modes and kinds of computational modelling activities done by Santos & Ogborn (1994) and also elements of the P.O.E. (Predict Observe Explain) methodology (Tao & Gunstone, 1999). These elements appear "diluted" in many fields of the AVM diagram and their stages, in the dialectic process of its development.

In the teaching activities of the exploratory mode, we motivate the student to question him/herself about the existing relationships among the many variables involved, driving him/her to constantly question about the effects of his/her actions upon the results generated by the model. This questioning can usually be described as: If I alter "this" what happens to "that"? This causal underlying reasoning acts as backround to the promotion of interactivity. In the expressive mode teaching activities, the AVM diagram was conceived to serve as an heuristic tool to the develpoment of computational models applied to teaching.

Example

In figure 2, an example of AVM diagram is given. It is just an example, not an exemplar. It was made by an introductory college physics student, in the expressive guided mode, has inadequacies in the scope of physics, for example, the assumption that the electric current in the circuit increases during the charging process of the capacitor. This AVM diagram was chosen as example because it illustrates well the difference between known results (which we assume as true in the designing/analysis of the computational model), and the predictions (answer attempts to the focus-questions). In an AVM diagram developed by someone who knows the content, and, therefore, who previously knows the answers to the focus-questions, the results obtained and the predictions may superimpose each other.

List of references

Araujo, I. S. (2005). *Simulação e modelagem computacionais como recursos auxiliares no ensino de Física Geral* Doctoral Thesis, Institute of Physics, Federal University of Rio Grande do Sul, Porto Alegre, Brazil.

Gowin, D. B. (1981). Educating. Ithaca, N.Y.: Cornell University Press.

Camiletti, G. & Ferracioli, L. (2002). A utilização da modelagem computacional semiquantitativa no estudo do sistema mola-massa, ***Revista Brasileira de Ensino de Física*** (Brazilian Journal of Physics Education)**, 24** (2) 110-123.

Halloun, I.(1996). Schematic modelling for meaningful learning of physics. *Journal of Research in Science Teaching,* **33** (9) 1019-1041.

Moreira, M. A. & Buchweitz, B. (1993). Novas estratégias de ensino e aprendizagem: os mapas conceptuais e o Vê epistemológico. Lisboa: Plátano Edições Técnicas.

Santos, A. C. K. & Ogborn, J. (1992). A model for teaching and researching into a computational modelling. *Journal of Computer Assisted Learning,* **8,** 67-78.

Santos, A. C. K. & Ogborn, J. (1994) Sixth form student´s ability to engage in computational modelling, *Journal of Computer Assisted Learning*, **10**, 182-200.

Tao, P. K. & Gunstone, R. F. (1999). The process of conceptual change in force and motion during computer-supported physics instruction. *Journal of Research in Science Teaching*, **36** (7) 859-882.

Figure 1 - **A**daptation of the epistemological **V** to computational **M**odelling

CONCEPTUAL DOMAIN

Beliefs

World views; general and comprehensive deep beliefs about the nature of knowledge underlying the development of the computational model.

Theory(ies), principle(s), theorem(s) and law(s)

Organized set of principle(s) and concepts linked to the phenomenon of interest and to the objects and/or events of study that guide the construction of the computational model. Statements of relationships among concepts that orient the elaboration of the model explaining how one can expect the events or objects in study to present or behave themselves.

Idealizations/approximations (context of validity)

Simplifications assumed in the elaboration of the physics model, seen as a structural and non specular analogous of the phenomenon it represents.

Entities/ signs

Objects composing the system to be modeled and objects which characterize the external agents that interact with the system, as well as their respective symbolic representations.

Concepts: Variables/Parameters

Properties and state descriptors related to the entities which will constitute the computational model.

Relationships

Mathematical and/or propositional relationships involving the variables and parameters of the physics model.

Known results

Some known results which will allow for the initial validation of the computational model.

Predictions

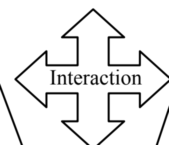
Answer attempts to the focus-questions before the construction or exploration of the computational model.

Phenomenon of interest

Definition of the phenomenon to be approached.

Focus-question(s)

To be answered through the building/analysis of the computational model.



Problem-situation

Description of the situation/event related to the focus-questions which contextualizes the phenomenon of interest.

METHODOLOGICAL DOMAIN

Possible generalizations and expansions of the model

Generalizations on the applicability of the structure of the mathematical model and expansion of the physics models as to include variables and relations not defined previously (changes in idealizations and principles), broadening its context of validity.

Claims of the model

Statements that answer the focus-question(s) and which are reasonable interpretations of the records and representations supplied by the model; evaluation of the predictions.

Model validation

Comparisons between the known results with the ones generated by the computational model, observing whether the relations already established between variables are being verified.

Modelling categorization

a) concerning the mode: exploratory or expressive (model construction);

b) concerning the kind: qualitative (linguistic), semiqualitative (casual relations, non-mathematical), quantitative (mathematical);

c) concerning the form of implementation/interaction: usage of metaphors, manuscript equations, equations defined in programming language, etc. The computational tool used must be indicated whenever possible.

Representations

Graphs, animations, tables and other ways of transforming registers done in the computational model.

Interactive elements

Elements (sliding buttons, rolling bars, etc.) which compose the computational model and are associated to variables and/or parameters, whose manipulation helps to answer the focus-question(s).

Records

Which observations are made (in the computational model) to try to answer the focus-questions (data involved).

Figure 2 - AVM diagram for building a RC circuit model from the point of view of a beginner student (notice the errors in the predictions)

CONCEPTUAL DOMAIN

Beliefs
Models which reproduce the dynamic behavior of an electric circuit can be designed.

Theory(ies), principle(s), theorem(s) and law(s)
The principle of conservation of energy;
Kirchhof's Network Laws;
Ohm's Law.

Idealizations/approximations (context of validity)
The conducting devices are connected by wires of negligible resistance;
The source has no considerable internal resistance;
There are no "losses"of the capacitor's stored charge to the media;
Electrical current continuity.

Entities
Wires; Capacitor; Source of direct voltage; Ohmic resistor

Signs
Electric current = i; electric charge = q; electric tension in the capacitor = V_c, in the resistor = VR, in the source = V; Electric resistance = R; Capacitance = C; time = t.

Variables	Parameters
t (s)	V (V)
i (A)	R (ohms)
q (mc)	C (F)
V_c (V)	
V_R (V)	

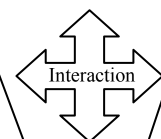
Relationships
$V = V_R + V_C$; $V_R = R.i$; $V_c = q/C$; $i = dq/dt$

Known results
For $t \to \infty$ and $V \neq 0$, $i=0$
The graph q x t, has the form of an exponential

Predictions
1) V does not influence, and the bigger the resistance, the longer the charge/discharge time;
2)Increasing R, it takes longer time to charge; increasing V, less time;
3) The current decreases in the discharge and increases in the charging process.

Phenomenon of interest
Electromagnetic magnitudes' variances in resistive and capacitive electrical circuits.

Focus-question(s)
1) What is the role of R and V in the charge/discharge time of the capacitor?
2) What is the behavior of q(t) if we vary R or V during the charge/ discharge time of the capacitor?
3) How does the current vary in the charge/discharge process of the capacitor?



Problem-situation
The analysis of the dynamic behavior of a RC circuit during the charging/discharging process of the capacitor.

METHODOLOGICAL DOMAIN

Possible generalizations and expansions of the model
The model could be expanded so as to consider the resistance of the wires and of the source. We could express C as a function of the area and model the case of a capacitor of movable plates. The model as it is, in the discharge process exhibits a dynamic behavior similar to the radioactive decay one.

Assertions of the model
1)The higher R or V in the circuit, the greater will be the time needed to charge/discharge the capacitor;
2) increasing (reducing) R the variation rate of the charge with the time, that is, current increases (decreases) as well as the value of the maximum charge which can be stored in the capacitor;
3) In the charge process, as in the discharge one, the current starts at a maximum value (positive or negative, respectively) and, as time goes by, it tends to zero.

Model validation
The known results are achieved with the model.

Modelling categorization
a) concerning the mode: expressive
b) concerning the kind: quantitative;
c) concerning the form of implementation/interaction: manuscript equations (Modellus).

Representations
Graphs: q x t; i x t

Interactive elements
Scrolling bars: V; R;
Initial values input: q(s).

Records
i(t); q(t)