An “imagination” tool to accelerate analogue electronics learning

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Abstract
This paper presents a proposal for a software application to accelerate analogue electronics learning.

Keywords
Analogue electronics, Computer aided learning, Creativity, Imagination.

Introduction

Today’s students have different skills and expectations.

We need to capture the fun and rate of learning experienced by people playing XBox games.

There is very little reliable research about the value of computer aided learning.

Learning is a process, so we should try process improvement methodologies that have proved successful in other domains.

PART 1: BACKGROUND

The problem

I am new to teaching. During my first 15 months I have been struck by my students’ unwillingness to learn topics to a deep level.

This teaching practice paper appeared at the 2nd annual conference of Computing and Information Technology Research and Education New Zealand (CITRENZ2011) incorporating the *24th Annual Conference of the National Advisory Committee on Computing Qualifications*, Rotorua, New Zealand, July 6-8. Samuel Mann and Michael Verhaart (Eds).

In the case of electronics this means that students have been reluctant to move beyond memorising the required “boiler plate” circuit configurations and associated formulas.

It seems that many students treat their coursework as an exercise in compliance. Where is their enthusiasm? What is going wrong?

On reflection

Perhaps for our students electronics is a much more intangible topic that when I was a student. Do they lack the skills and experience to engage?

Very few of our students come to us as electronics hobbyists. When I was working towards an NZCE, I was studying part time. The block courses I attended at the CIT (Central Institute of Technology) were preceded by the practical experience of working as a cadet telecommunications technician. I arrived at the CIT with experience of commissioning electronic systems, and assisting experts in the analysis of faults.

A number of questions then came into focus:

- Do these students have any experience at deep learning?

- Should we be explicitly teaching deep learning skills?

- Why do students seem so unwilling to commit their imagination and creativity to their learning?

- How do we support students to move from NCEA expectations to industry expectations?

- How can we demonstrate that analogue electronics can be fun and fascinating?

Is imagination the key?

There has been a lot of research and writing about surface learners. However the advice on turning surface learners into deep learners tends to be too high level to apply directly.

My reading is that the common factors are *imagination and creativity.*

So in the case of analogue electronics, how do we deliver a learning environment that makes applying imagination and creativity the natural thing to do?

My position is that we should start by making sure we do a very good job of explicitly equipping our students with abstract models for analogue electronics.

I have four reasons for considering that abstract models would provide an excellent imagination and creativity framework:

Reason 1: My own learning experience

When in the third form (year 9) the late Ken Farnsworth, the teacher in charge of the electronics club, taught me a very useful abstract model for simple electronic circuits. He provided ways of visualising components. Two examples:

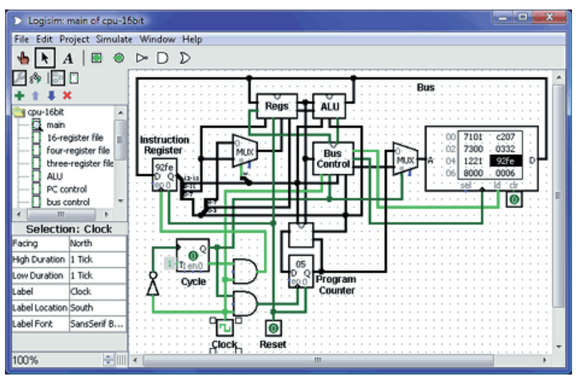
- For example, capacitors can be visualized as electron traps. At each end of a capacitor there is something like the turning area at the end of a cul-de-sac. For a while a capacitor seems like a piece of wire, but when the turning area has filled up,

- then the current stops. The bigger the capacitance, the bigger the turning area.
- Inductors contain electron conveyor belts. Consequently when electrons enter an inductor, there is a delay before they start coming out the other end. Conversely, after the electrons stop entering inductor, there is a delay before they stop emerging from the other end.

Even though this is a very simple model it took me a long way. For example when resonant LC circuits were presented in class at the CIT, there were two students that got it instantly: the class genius, and thanks to the Farnsworth model, me.

Reason 2: The success of abstract models in digital electronics

Digital electronics is a specialisation of analogue electronics. The chip designers have completely hidden the low level implementation, consequently circuit designers can focus on the Boolean abstraction.



There are some excellent tools for learners of digital electronics, Logisim for example. Logism is a very accessible software application that demonstrates the dynamic behavior of digital circuits.

Reason 3: Professor Anant Agarwal's lectures for the 6.002 Circuits and Electronics course at the Massachusetts Institute of Technology

This is a fantastic exemplar of electronics teaching. The first lecture covers the layers of abstraction in electronics. From then on Agarwal introduces the topics with the abstractions, and then drills down to the components. Given that first year students no longer arrive with knowledge of electronic components, perhaps this is the more relevant approach?

Reason 4: The master practitioners use abstract models.

When discussing the misuse of computer based design tools, Bob Blauschild, a designer at Signetics, said that an engineer that is tweaking a design is not learning anything without asking these questions:

1. What do I expect the result to be if I make this change?

2. Was the last result different than I expected, and if so, why?

Electronics text books are necessarily crammed with formulas. However Barrie Gilbert, of translinear amplifier fame, said that he started every monolithic design with four basic truths:

1. Like elements match well.

2. V=IR (ignore this at your peril).

3. dV/dT=I/C, or its integral form CV=IT.

4. $I_C=I_S^{(Vbe/Vt)}$ for bipolar out of saturation;
   $I_{DS}=K(V_{gs}-V_{th})^2$ for MOS in its saturation region.

He went on to say that "while not academically too respectable" the "prod and poke" approach that he promotes is more likely to yield results than a formal synthesis procedure.

Clearly Blauschild and Gilbert are talking about the application of wisdom, and they were using their imaginations to visualise circuits.

Give it a go

I thought I could get this across in a few quick group exercises; this was not the case. It quickly became clear that developing these mental skills is very hard work as it is such a large leap from their tried and true strategies. This was going to be a challenge that would impact on the lesson plans.

So how to tap into the student's imaginations and creativity? Ken Robinson's TED presentation about how schools kill creativity was ringing very true.

PART 2: MAKE A PLAN

Back to the drawing board

Having been involved in the development of software to represent complex data and systems, a software "imagination" tool seemed to be an obvious avenue.

However the studies that I found offered no encouragement. They indicated that there is no significant difference in outcomes between CAL and traditional learning methods. Is this the reason for the apparent lack of innovation in computer aided learning? Even in distance learning.

On looking into these studies it quickly became clear that majority are flawed: they are multivariate, but not conducted using multivariate techniques. In particular I see no value in comparing the overall outcome between two samples; this ignores that the majority of students are strategic, and will only put in the work required to meet their objectives. Also of concern is the small sample sizes in these studies. One notable exception is the rigorous paper from Dorneles et al.

In the absence of a body of relevant education research, I returned to what I know: process improvement. Surely we can view learning as a process, so let's apply a process improvement methodology that has proved successful. For me the *six sigma* methodology is the obvious candidate. I have applied this methodology to improve outcomes for software development and IT operations teams.

Since this is a new sub process, the Six Sigma DMADV methodology is appropriate.

The methodology calls for the following steps:

- **D**efine design goals that are consistent with customer demands and the enterprise strategy.

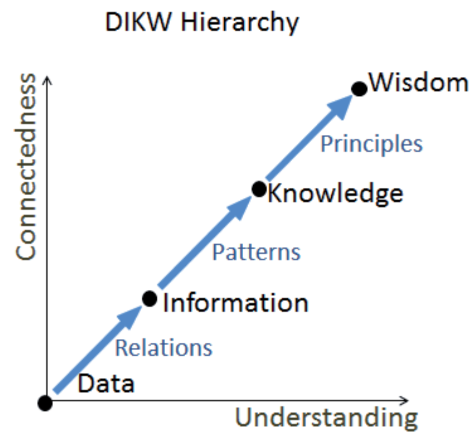
- **M**easure and identify CTQs (characteristics that are Critical To Quality), product capabilities, production process capability, and risks.
- **A**nalyse to develop and design alternatives, create a high-level design and evaluate design capability to select the best design.
- **D**esign details, optimise the design, and plan for design verification. This phase may require simulations.
- **V**erify the design, set up pilot runs, implement the production process and hand it over to the process owner(s).

Define

What is the ideal outcome, and how do we express it?

When looking at people-centric processes, the Bellinger et al representation of the DIKW hierarchy has often proved very useful.

Instead of the usual pyramid, Bellinger uses a graph to represent the DIKW hierarchy. Starting from data, once the relationships between the data items are understood, then we have information. When the patterns within the information are understood, then we have knowledge. Once the underlying principles underpinning a body of knowledge are understood, then we have wisdom. Data, information and knowledge concern the past and present. Wisdom supports reasoning about the future.



The first step is to map the person capabilities in the problem domain to the points on the DIKW graph.

For a first year analogue electronics course the data consists of:

- The names and symbols of the basic components.
- Some basic "boiler plate" circuits.
- Elementary circuit theorems.

Learning how and when to apply the circuit theorems constitutes the relations that transform the data into information.
Learning why basic circuits behave the way that they do constitutes the understanding that transforms the information to knowledge.

The understanding of the underlying patterns that enable the predictions required to debug faulty circuits, and to design variations on themes maps to Wisdom on the DIKW diagram.

For the first year electronics assessments that I am aware of, students to have reach the information point in order to pass. To attain an A pass demands reaching a point between information and knowledge.

My goal is to raise the pass point from information to knowledge.

What does this objective mean for the stakeholders?

For our students, who are the key stake holders, this objective delivers capabilities rather than general knowledge. They should be able to design simple interface circuits, and approach fault finding in a systematic manner.

The IT School has effective strategies for encouraging students to take responsibility for their learning, but this takes time. We would all like to find ways to accelerate the process. Especially for a first year subject like electronics that is a vital prerequisite for some year two subjects.

Measure

Since the goal is to move the pass point up the DIKW line, the CTQs must capture any movement on this graph. The ultimate CTQ would be to capture the proportion of the marks gained in the final examination that are awarded for demonstrating knowledge rather than recall of information. This CTQ is however well down the track from the proof of concept this paper is promoting.

For a proof of concept the approach used by Dorneles et al seems appropriate. Here a lesson has a pre and post test.

If material is presented in a way that makes it more tangible, and students are able to learn more rapidly, then we can expect that the learning experience will be more enjoyable and stimulating. This could be surveyed.

Analyse

This is where the journey really begins. We start with questions like: What would a good outcome look like? What is getting in the way? What can be done to make a difference?

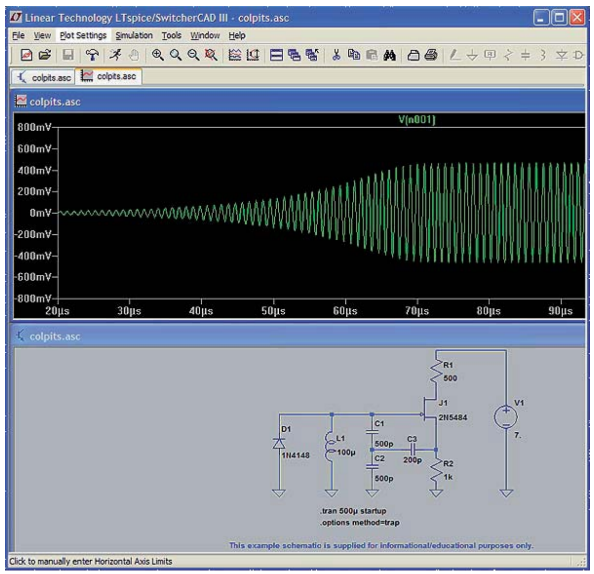
My ideal outcome
A software application that will jumpstart the process of learning how to visualize and reason about electronics using abstractions. It will be fun to use.

Question 1 – How to fit more into a course
From the DIKW diagram it was clear that the focus needs to go on to the patterns that once understood transform information into knowledge. But how to get this across without making the course longer?

A solution would be teach the relations and patterns concurrently; but how?

Question 2 – What software visualisation tool to use
How to provide a visualisation for a circuit’s behavior? My first thought was to use SPICE. SPICE is an

excellent modeling system for analogue electronics, and is frequently used by design engineers. Most modern electronics texts provide SPICE models to illustrate the behaviour of circuits, and some courses make use of this tool. However SPICE does not provide a framework for presenting abstract models. It can certainly do a fantastic job of revealing the dynamic behaviour of a circuit; but it does not illustrate the contribution that each component makes. Each component appears as a lifeless symbol on the schematic.



An observation

There was an excellent model right under my nose. When we observe teenagers in our households playing XBox games:

- We see total concentration
- The challenges are undertaken with determination and tenacity. Despite the exasperation of failure, players really stick with and repeat challenges until they make it through without having to *respawn*.
- Mastering virtual worlds demand players really use their imaginations to build a map of the virtual world and to develop navigation and survival strategies. The key point: it appears that these tasks which involve acquiring both relationships and patterns are performed **concurrently**!

If our students approached their work with this commitment and tenacity, they would all be A students.

Next question: how to capitilize on this?

How about a virtual *circuit world*? Can we evolve from first person shooter games to a first person designer games.

My thinking is that we must go beyond displaying static schematics. We must animate the circuit schematics with visual abstractions.

A sobering realisation

An application that is as slick as an XBox game will be perceived as average. Anything less, even if a big improvement over existing tools, will be perceived by the XBox generation as below par. So to raise the bar, we have to meet a much higher standard.

Design details

I have settled on an XBox style proof of concept application. The plan is to implement an application that will provide a dynamic graphical representation of the Farnsworth model, plus some extensions.

Over time I had to extend the Farnsworth model. For example, when dealing with phase shift in filter circuits it proved useful to view capacitors and inductors as rechargeable batteries, all be it batteries with a very limited charge capability. Just like regular rechargeable batteries, with capacitors electrons come out the same end that they entered. Inductors are peculiar rechargeable batteries though; the electrons come out the opposite end from which they entered.

Due to my rural background I came up models for semiconductor devices based on drafting races from various stock yards that I have worked in. I am wondering about something more universal: how about using motorway junctions as a model?

The Microsoft DirectX 3D engine will be used, with a view to eventually building an XBox application.

The open source NGSPICE application will be used to provide a backend modeling engine.

Verify

When testing this visualisation tool, I will be interested in two variables.

1. The impact of presenting a method that students can use to visualise the operation of a circuit, and imagine effects of changing the inputs and component values.

2. The difference between a traditional workbook and an *imagination enabled* e-workbook.

This will require the sample to be split into three groups.

<table>
<tr><td>Group A</td><td>Group B</td><td>Group C</td></tr>
<tr><td></td><td colspan="2">How to use the visualisation tool.</td></tr>
<tr><td colspan="3">Pre test</td></tr>
<tr><td colspan="2">Topic content.
Existing course material.</td><td>Topic content.
Visualization tool based e-chapter.</td></tr>
<tr><td colspan="3">Post test</td></tr>
<tr><td colspan="3">Survey</td></tr>
</table>

The next iteration

The evidence will be used to build a case for funding another DMADV cycle. The likely key activities for a second cycle are:

1. Turning the proof of concept application into a properly engineered learning tool.

2. Analysing the degree to which the assessment bar should be raised. This would entail altering the assessment to test for knowledge in line with the goal of moving the pass point up the DIKW hierarchy.

PART 3: HERE AND NOW

Isn't analogue electronics a thing of the past

I have been asked "Why put the effort into analogue electronics? Isn't everything digital now?"

Firstly, every digital device needs a power supply, and power supplies are analogue devices.

The main reason is that the physical world is analogue, and there is a rapidly expanding range of devices and techniques to interface to digital systems.

According to DataBeans, the global Analogue IC market will reach almost $45.2 billion in global revenue in 2011, growing 10% annually on average until the year 2016. Surely that is a projection that should mean something to New Zealand Inc!

Why present this paper now

Why am I presenting this paper now rather than waiting until I have empirical data to share?

The answer, I need your help:

1. To verify the proof of concept I would like a sample of at least 300 first year students. A sample of this size will require the cooperation of several polytechnics. So I am calling for collaborators.

2. I have become very interested in the way in which people visualise complex systems. Please, tell me your stories. Your collective wisdom will then help in the design of the application

Acknowledgements

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