Teaching about water supply*

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Abstract

This paper discusses some theories of constructivist learning and the relevance of software models with experiential learning. The applications of Empirical Modelling for two different kinds of teaching models are explored and compared against implementations using procedural languages. Using a series of models of a water supply system, the paper demonstrates the use of an Empirical Modelling approach to teaching abstract concepts and some problems associated with implementing a model of a cyclic system using current empirical modelling tools.

1 Introduction

In today's classroom, many high level concepts are presented to students as overviews of systems. Such an instructivist approach rarely pay any attention to the processes that occur in these systems and how the system function, and inline with the "kill-and-drill" (Roe, 2002) approaches that many educational institutions have been accused of, students are often expected to accept at face-value "facts" about the systems provided.

The water supply system in a water scarce country is one victim of such an approach. While traditional instructivist teaching materials do a good job of informing students the various processes involved in the system and how they are connected to one another, they completely ignore the dependencies that exist between these processes. Thus a concept such as 'if we do not use water wisely, there will not be enough to use in future' is just a statement that bears no relationship with the reasons that make it true.

This paper begins by briefly introducing the case study for the model (Singapore) and why Empirical Modelling (EM) concepts can be used to model it. The next section looks at a constructivist approach to learning and how the use of software models and EM concepts fit into it. Lastly, the paper looks at an EM model that models the case study.

2 Water supply and EM concepts

Supplying potable water to an entire country is a multi-stage process that starts with precipitation and ends with the user. While this is strictly a linear process, it can be thought as a cyclic one by including natural phenomena such as evaporation and the weather, thus completing the water cycle. For the purposes of this study, the water supply system for Singapore has been chosen as a case study.

2.1 Water supply in Singapore

Singapore was chosen to be the case study because of its unique situation of being a small country with a big population. As a result, alternate sources of water need to be explored as its demand cannot be met by precipitation alone. Currently, raw water is imported from a neighboring country and potable water is also produced from a Reverse-Osmosis (RO) plant which recycles waste water (effectively an inexhaustible source limited only by the plant's capacity).

It is estimated that about 4 million cubic metres of potable water is needed daily and about half of this amount is imported. As a result, the potable water that is supplied is a mixture of output from the RO plant and the purification plants.

As a tropical country, Singapore experiences periods of dry weather and this can (and have in the 1960s) lead to the country not having enough water to meet demand. Thus in order that water supplies are kept at a healthy level, the levels of water from alternate sources need to be constantly adjusted to maintain this dynamic equilibrium.

2.2 Water supply and EM concepts

A water supply system for a country encompasses many observables and dependencies. At its highest, one can expect to observe things like purification plant output, the amount of water currently available at a reservoir, or the demand from users. Many of these observables are dependent on each other, for example the output of a purification plant depends on

*My selected weighting for this coursework is 60% paper, 40% model the demand level and its capacity. In EDEN such a dependency can be written as:

*Plant_output is min(maximum_capacity, 70% * demand)*

This is a persistent dependency that has to hold true regardless of the actual values for maximum capacity, demand and plant output. If this model were implemented in a procedural fashion, the modeller/developer would have to be responsible for monitoring the value of *Plant_output* in case either *maximum_capacity* or *demand* changes its value. Clearly this diverts his focus from the actual modelling to maintaining the integrity of the model.

Spatial realism has been largely ignored in this model because its goal is to teach abstract concepts such as "the importance of saving water" to school children and not as an accurate model of a real life system for engineers. An accurate model of the system would have to take into account the fact that the system consists of a huge network of pipes and as such, it is difficult to model accurately and is likely to go over the heads of the intended audience in this instance.

In building the water supply model, it is more helpful not to have explicit agency because it is unlike models which have many instances of the same agent where one is interested in "using a single process definition to describe a generic mode of behaviour, and allowing many instances of a particular type to participate in a system" (Beynon, 1986). Here, there is only one instance of each process (as a result of not having spatial realism), hence it is sufficient to look at the system as a set of dependency-based interaction between processes.

2.2.1 Cyclic systems

The model described so far is a largely linear supply-and-demand system, with no notion of any form if feedback. One of the unique features of this model is that it attempts to model the natural water cycle as a means of topping up reservoir water reservoirs by way of precipitation and a means of draining water from reservoirs by way of evaporation. These two processes are dependent on each other and also on the weather which in the model was abstracted by the temperature observable. The processes of evaporation and precipitation are inversely related to each other and both are dependent on the temperature observable. In turn, the temperature is affected by both precipitation and evaporation. At the time of writing, the author was informed that such a cyclic model has never been built using current EM tools before, so this model also serves as a platform to explore if the tools are suitable for modelling cyclic relationships.

Procedural formalisms and hence languages have no problem with cyclic relationships and assignments such as "a=a+2". In a definitive formalism however, it has been declared in Beynon (1985) that such circular definitions are "meaningless" and that it is "necessary" to prevent this from happening. The implication of this is that the following sequence of definitions, which define a circular relationship between the observables *a*, *b*, *c*:

a is b + 1;
b is c + 2;
c is a + 3;

is impermissible because c is defined in terms of itself.

In this model, the dependencies between the observables temperature, evaporation and precipitation are:

1. *current_evaporation is max (0, 0.001 * current_temperature);*

2. *current_precipitation is max (0, 30/current_temperature + 0.01 * current_evaporation);*

3. *current_temperature is current_temperature - (current_precipitation/80) + current_evaporation;*

(Note that these dependencies are only meant to be an extremely simple representation of the actual dependencies, which to the best of the author's knowledge, have yet to be discovered by meteorologists.)

Procedurally, nothing is wrong with the above three statements. However, they are not allowed in a definitive environment. In order to overcome this constraint, a mix of definitive and procedural approaches in EDEN. Definitions 1 and 2 can be left as they are but in order to close the loop to form a cyclic dependency, statement 3 needs to be declared procedurally rather than definitively and current_temperature must be updated at regular intervals or at certain defined events (such as when some other observable changes its value, for instance).

One can get away with the above method to close the loop in a system that progresses in discrete time intervals, such as our water supply model. Unfortunately, this method may not be applicable to a system that does not advance in discrete time steps, such as in analogue electronic circuits exemplified by the circuit for a single op-amp band-pass filter in Figure 1.

In this example, the output of the op-amp is dependent upon the input at the two input terminals, but

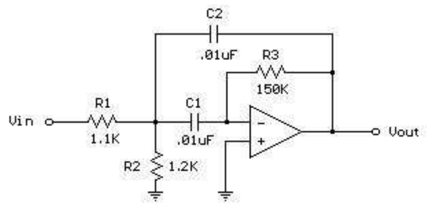

Figure 1: A single op-amp band-pass filter exemplifying a system with feedback. From Bowden (2005)

the input at the inverting terminal is also dependent upon the current output. Here it is not desirable to apply the procedural method of closing the loop because it can potentially introduce problems involving sub-sampling and aliasing.

3 Computers and Learning

As computers become more and more affordable, their presence in the classroom become more and more noticeable. In the beginning, computers in the classroom served merely as glorified screen projectors whose main purpose was to save the teacher from having to print transparency slides. Gradually, most students have individual access to a computer whether at home or in school and this created a market for educational software. Performance wise, a noticeable improvement in computer technology has been in multimedia. From its humble beginnings in vector graphics, computers are now able o render photo-realistic graphics and animations. These were deemed to be a powerful tool for educators as they can deliver content to students better than static text and images on paper can. As the novelty of using computers wear off, educators are once again faced with having to find new ways to use computers in the classroom.

3.1 Constructivism

Unfortunately current approaches tend to result in spoon-feeding (of which the education systems in UK and Singapore have both been accused of) where students merely accept the information presented to them as truths, without exploring the reasons that make it so. In recent years, the educations systems of both UK and Singapore have made conscious steps to move away from such an instructivist approach to a more constructivist approach. In a constructivist approach, the learner "construct[s] their own reality or at least interpret it based upon their perceptions of experiences, so an individual's knowledge is a function of one's prior experiences, mental structures, and beliefs that are used to interpret objects and events"(Jonassen, 1994). An advantage of this approach over an instructivist approach is that there is not anyone to make assumptions about the learner's past knowledge so the learner can proceed at his own pace.

One theory of constructivism is constructionism which was described as "a context where the learner is consciously engaged in constructing a public entity"(Harel, 1991). The idea behind this was to get the learner to build entities so as to allow them to build internal knowledge in the appropriate domain. Papert himself created Logo which is a tool that allowed young children to learn mathematical concepts by drawing shapes defined mathematically. It was found that Logo was not as successful as it was hoped to be because students were not able to grasp all the concepts they were supposed to learn.

3.1.1 Experiential Learning

Apart from constructionism, there is another flavour of constructivism: Experiential learning, which is defined broadly as learning by experiencing. Kolb's learning cycle(Kolb, 1984), perhaps the most commonly used descriptive model of experiential learning is a four stage model (Figure 1) which suggests that whenever experimentation occurs, the learner gains some sort of concrete experience relating to the experimentation. After which he reflects upon this experience on a personal basis, during which the next process, abstract conceptualization occurs where he derives abstract, general rules about the experience to make sense of it the cycle then starts again with the next occurrence of active experimentation.

Although Kolb tried to identify different types of learning, the uni-directional nature of his learning cycle suggests that all learning is a result of the same sequence of activities. This problem is addressed in the Experiential Framework for Learning (EFL) described in Beynon (1997). The EFL describes various learning activities and how they complement one another. In particular, it allows for both gaining theoretical knowledge through experimentation (exploring a model) and using theoretical knowledge to facilitate experimentation (building a model).

3.2 Use of Models in Education

In the past few decades, advances in human-computer interaction have mostly focused on delivering richer content via multimedia. As a result, educational software followed the same paradigm and they threw an ever-increasing amount of audio and visual simulation at the user, effectively creating a one-way flow of information. This is exacerbated by the fact that traditionally, "all leaning and knowledge is fundamentally mediated by language"(Beynon, 1997). The popularity of procedural programming languages such as java over declarative ones like prolog also means that most software are written using procedural languages. The problem that this presents is that the software does exactly what the programmer tells it to do, and any interaction with the software on the part of the learner is dictated by the programmer, leading to an instructivist approach to using the software.

Today, educators around the world believe that the constructivist way of teaching is the way to go, exemplified by this quote by Janet Lim:

"*Good teaching involves the student*"(CDTL, 1998)

Ideally, learners should be allowed to interact and experiment with the relevant artefacts related to the abstract knowledge they wish to gain. For instance, there is no doubt that medical students learn better by dissecting a cadaver than by looking at pictures in textbooks. However, this is not always possible such as in the case of a country's water supply where it is not feasible to experiment on the actual system. In such cases computer models offer an attractive alternative.

3.3 Exploratory vs. Expressive models

Broadly speaking, a model is something which is used to think about the thing it represents. (OLTC) classifies software models into Exploratory and Expressive. In an exploratory model, the learner uses a model that someone else built. In such a model, the learner gains abstract knowledge by experimenting (exploring) with the model and any such knowledge gained is usually pre-determined by the developer of the model. On the other hand, expressive models allow learners to apply their own abstractions onto it, thereby building the model.

It is tempting to conclude that learners should be asked to explore exploratory models before embarking on a building an expressive model. After all, it is hard to see how one can build a model without already possessing some knowledge in the relevant domain. Surprisingly, studies have suggested that preceding expressive modelling with exploratory modelling does not necessarily lead to better understanding of the domain(Webb, 1994), which seems to imply that all model building should be left to the learner. Such an approach can potentially be time consuming. Hence a balance needs to be struck. Webb has conceded that although 9 year old students are able to undertake the modelling process, they need to be "working with subject matter with which they are familiar and knowledgeable" (Webb, 1994).

In view of this, it is suggested that teachers should supply a "seed model" which learners can explore to obtain the minimal level of knowledge about the domain. After this bare minimum has been achieved, learners can then extend the model by building on it to gain more in-depth knowledge and experience about the domain.

3.4 Empirical modelling vs. Java: A modelling perspective

This section contrasts the use of use of empirical modelling tools with procedural programming languages such as Java for use in building models used in education.

The nature of software is such that the developer gives it a set of rules according to which the software must behave, and the set of rules must have been pre-determined (specification) before the software is even being written (implementation). Such an approach poses no problems if one is building a purely exploratory model, and indeed many such examples exist: almost all games on the market today such as WarCraft, Civilization are written in procedural programming languages like C or C++. Here there is no problem because gamers are supposed to play by the rules dictated by the developers in the name of fairness.

If it were expressive models that we are interested in, then we can expect to face some problems if procedural languages are used:

1. Java programs are not flexible in that once written, it is difficult to make changes or add on new features as this often involve examining every line of the code to ensure its integrity. One also needs to have substantial programming skills to program a decent model with Java.

2. Java programs are based in terms of a pre-defined set of functionalities. Therefore there are no unexpected results, only instances of incorrect experimentation. There is also no way for the student to interact with the model beyond

the outlets that have been provided for the developer.

Beynon (1997) describes some features of Empirical Modelling that solves the above problems:

1. By developing models that allow “flexible adaptation, extension and reuse, even by users who are not computer specialists”, learners can concentrate on model building and not spend too much time on checking the integrity of the model.

2. Emphasis is placed on the creation of artefacts rather than applications which perform a predefined set of functions.

It is agreed that a good teacher is one who “does not copy wholesale from existing textbooks and reference sources” (CDTL, 1998), EM models may just allow time-strapped teachers to spend more time adapting models to their specific needs rather than re-using out-dated or generic models.

4 Modelling Study

4.1 Aims of the model

The aim of this modelling exercise was to produce a series of models with which students can learn about sources of Singapore’s water supply and why they should use water wisely. It can be difficult for students to grasp the concept that water is a scarce resource in a country where potable water flows almost endlessly at the turn of a tap. By using a model, students can see how easy it is to disturb the dynamic equilibrium that keeps the water flowing from their taps, the role that Mother Nature plays in it an the time it takes for a disturbance to bring down the system.

The models were built as a series of models of increasing complexity. In line with the idea of a “seed model”, a teacher can supply the simpler models and student can be asked to extend them to a fashion similar to the next models in the series. In all the models, the goal is to be able to meet the demand for water and progression of time is in daily intervals.

4.2 Study 1 and 2: Initial seed models

Study 1 is the initial seed model that can be supplied to younger children. It is not an accurate model in terms of the data used and it is an over-simplistic view of the water supply system. Its purpose is to allow students to familiarize themselves with the concept of supply-and-demand which forms the basis of the water supply system.

Study 2 adds an additional source of water via imported water from a neighboring country and an additional drain on the store of water in reservoirs in the form of evaporation. This model can be used for students already familiar with the basic concepts of supply-and-demand, to whom we can introduce a multiple-source system. The evaporation process also serves to help students understand the impact of evaporation on water supplies in a warm climate.

4.3 Study 3: The water cycle

Study 3 moves away from thinking about precipitation and evaporation as independent processes by introducing a simple abstraction of the weather in the form of ambient temperature. Together the 3 form the natural cycle. This model seeks to create a relationship between the day’s temperature, the amount of water evaporated from reservoirs (which are still, open air bodies of water) and the amount of water falling as precipitation.

This model is the first in the series that truly allow modeling for expressive learning. The previous two models were meant to teach the generic, abstract concept that demand is met when supply exceeds demand, hence there is not much room for expressive learning. Students can be asked to re-define the dependencies in the water cycle to better understand how the processes are related. The model can also be extended to add more dependencies to it. For example, students can be asked to investigate the effects of pollutants in the air on the level of precipitation by adding dependencies to the model.

4.4 Study 4 and 5: Real world limitations

Study 4 introduces a new source of water and upper limits on reservoirs and processing plants, in line with the real world limitation that such facilities do not have infinite capacities and they should not be left idle or empty. This results in supply levels of processes depending on not only the process’s maximum value, but also on other processes’ maximum values as well.

These 2 studies contain the richest set of dependencies in the series and like study 3, students can extend them by adding dependencies or even processes. All the models in this series are easily breakable in that although they all start out meeting demand, small changes can result in irreversible results. Through this set of models, it is hoped that students can learn about the delicateness of the water supply and the importance of using water wisely.

5 Conclusion

This paper highlighted the benefits of using an empirical modelling approach to develop models for use in the classroom through discussions of various constructivist theories. In particular, the benefits of experiential learning were highlighted and the paper showed how it links to learning with software models. It was concluded that in general, EM tools are better than procedural languages like Java for building educational models.

Through discussions of the implementation of a model of Singapore's water supply system and the water cycle, it was shown that although EDEN specifically disallows circular definitions, a mix of procedural and definitive approaches can circumvent this problem. Various problems presented by this suggested solution were also pointed out.

Further development of the water supply model could include future sources of water such as desalination. It is also conceivable that as special purpose notation can be created for students wishing to redefine the dependencies in the model.

Acknowledgements

I would like to thank Miss Boon Lin Tan, Manager (Community Relations) from the 3P Network Department of the Singapore Public Utilities Board (http://www.pub.gov.sg) for her invaluable help and time in enlightening me on current teaching methods and tools used to teach some of the concepts my model tries to teach.

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