What Are Simulations? – The JeLSIM Perspective.

1 Introduction

This white paper is the first of a series on simulations and their use in education. It lays the foundation for the other papers, providing a general overview of simulations, their scope, history and evolving role and looks at the position of JeLSIM tools and eSims within simulation world. The paper covers the following topics:

- Defining simulation – the essential features of simulation.
- The concepts and techniques involved in simulation and modelling;
- The uses of computer simulations;
- The boundaries of simulation – what is and isn't simulation.
- A critical review of recent attempts to widen the scope of the term simulation;
- JeLSIM and its position in the simulation world.

2 Defining simulation

Defining simulations is problematic, given the many perspectives of its users. The benefits of simulation are becoming more generally recognised in the e-Learning market, and attempts to capitalise on the positive overtones of the term have led to it being applied outside of its original meaning. To avoid confusion, it is important to clearly and unequivocally define the term and its usage within these papers. A typical dictionary definition from The Oxford English Dictionary describes simulation as:

"The technique of imitating the behaviour of some situation or system (Economic, Mechanical etc.) by means of an analogous model, situation, or apparatus, either to gain information more conveniently or to train personnel."

This paper is concerned with **computer** simulation and therefore the "analogous model" in the above definition is one that can be executed on a computer. Paul Fishwick, a specialist in simulation techniques, in his book "Simulation model design and execution"[1], describes computer simulation as

"*.. the discipline of designing a model of an actual or theoretical physical system, executing the model on a digital computer and analysing the execution output*."

From the educational perspective, Diana Laurillard in "Rethinking University Teaching"[2] states:

"A computer-based simulation is a program that embodies some aspect of the world, allows the user to make inputs to the model, and displays the results."

There is then, broad agreement from both simulation experts and educational users of computer simulations that the key features of simulations are:

1. **There is a computer model of a real or theoretical system that contains information on how the system behaves.**

2. **Experimentation can take place. i.e. changing the input to the model affects the output.**

2.1 A note on complexity of simulations

Some users of simulation would not define computer models of simple systems as simulation. There is little point, after all, in simulating a system for analysis and design that is already clearly understood. From the educational perspective Laurillard would set a level below which a simulation ceases to be useful. She says:

"*Simulations are useful in representing complex relations. There would be little point, for example, in simulating a model of an aspect of the economy, such as `increasing inflation leads to increasing unemployment` as the relationship is simple enough to understand from the description alone*."

Her view would probably be that the second part of the above definition should be amended from "experimentation" to "useful experimentation"? However, Laurillard is writing from the perspective of a teacher in Higher Education. The level of complexity at which a simulation becomes "useful" depends on the level and understanding of the user. What may be obvious to a more expert student may be novel and a difficult concept to a younger student or someone studying at a lower level.

In these papers, a major concern is with educational use of a simulation at all levels, any model, no matter how simple, which complies with the above definition, could be considered as a simulation.

3 Simulation modelling techniques

To fully understand what constitutes simulation and how they can be used in education, it is necessary to have a grasp of the processes and techniques used in producing and using a computer model of a system (simulation). A diagram of the process involved in simulation and modelling is shown below in figure 1.

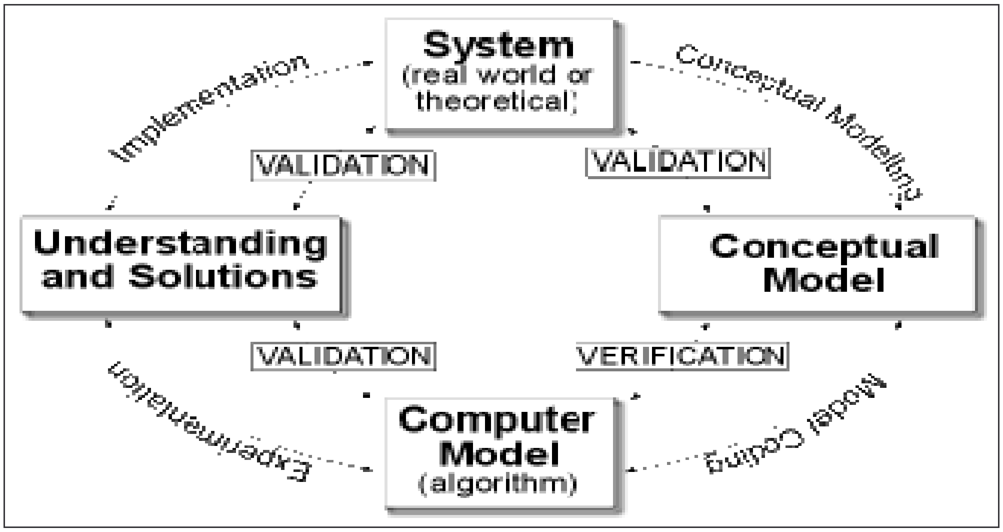

Figure 1 *The modelling and simulation process*

The process illustrated in the diagram can be applied to any system either real or theoretical. The aim of the modelling process is to be able to predict and understand the behaviour of the system under a range of conditions. The system modelled may be dynamic and exhibit a behaviour that changes over time or be in a steady state that can be perturbed by changing the system parameters.

3.1 Conceptual modelling

Conceptual modelling is the process whereby the modeller defines a simplified representation of a system. Approximations or simplifications (e.g. ignoring drag and rotation in a simulation of projectile motion) are introduced to reduce complexity, computational requirements or solutions time.

It is beyond the scope of this document to go into details of modelling. For any system there may well be a number of different ways in which a given system could be modelled, the modeller will make the choice based on the needs of a particular project. For some systems, there may be an analytic solution and a set of equations that define the model adequately, in others the computer must be used to approximate a solution. Other considerations in choosing a modelling technique include:

Time span: Models may be either
  - o ***dynamic,*** describing behaviours changing over time or
  - o ***static*** describing the system at a given instant of time and in an assumed state of equilibrium.
- **Dynamic behaviour:** Changes in a system over time can be represented as:
  - o ***Discrete Events*** where changes to the system take place in distinct steps or
  - o ***Continuous*** where the system evolves continuously.
- **Randomness:**
  - o A ***deterministic*** model generates the response to a given input by one fixed law, for a given input, it always provides the same output. A ***chaotic*** model is a deterministic model whose output is unpredictable

due to the sensitivity of the initial conditions (i.e. the starting state cannot be defined with sufficient accuracy). Conversely a
  - A ***Stochastic*** model picks up the response from a set of possible responses according to a fixed probability distribution and can thus simulate the behaviour of real systems under random conditions. (Techniques such as ***Monte Carlo*** are used for such models)

3.2 Model coding

During coding the model is converted to an algorithm that can be executed on a computer. The computer algorithm must be verified to ensure it matches the model and validated to ensure the output reflects the behaviour of the system. This is an iterative process repeated until a sufficiently accurate model is obtained.

The main ways of constructing computer models are:

- **Specialist Toolkits:** These are available for many different types of modelling e.g. Systems dynamics (Stella, PowerSim), Discrete event e.g. (Simul8, Arena)
- **Programming Languages: (**e.g. Java, C++ etc.) In which models are constructed from scratch.
- **Spreadsheets:** These provide a simple general purpose tool which can be used for less complex systems.
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3.3 Experimentation

Once the computer model is constructed, the modeller experiments with the model to solve problems within the system and to obtain a better understanding of the system. Techniques used at this stage include:

- **Sensitivity analysis:** This is used to test the robustness of a solution and to ascertain the effects of uncertain input data on the system outputs and behaviour.
- **Searching the solution space:** To search for an optimum solution or simulation state by repeatedly running a simulation is extremely time consuming and rarely practical. Techniques such as hill climbing and genetic algorithms have been developed to assist in this.
- **Validation of accuracy of results**: It is important to check the validity of results obtained and to ensure that bias from poor sampling is not introduced.

3.4 Implementation

After obtaining an understanding of the system, decisions may be made and actions taken which affect the real world system. The cycle of modelling may then begin again, as the original system is changed by these interventions.

4 The uses of computer simulation

Today, simulation has a range of uses in analysis, design, research, education, training and entertainment. The techniques described in the previous section grew out of research, and were originally used in design and analysis. Before the advent of graphics terminals, output from a simulation was usable only by the modeller and the discipline was very much the domain of the mathematically adept programmer. Once improved hardware provided better data visualisation, non-mathematicians (e.g. business mangers) were able to easily explore the solution space and the experimental stage of the simulation process became more generally accessible. Design and analysis using simulation was more widely used. With further advances in hardware and the ubiquitous availability of computers, simulations began to be used more in education, training and entertainment where the focus is on using the models to drive systems or to explore models and less on their construction.

4.1 Uses of simulation

Currently, most simulation use falls into the following categories:

1. **Research**
   Research into simulations is important in exploring the accuracy and utility of novel analytic techniques that may prove of use in design and analysis; it involves the derivation and verification of models of systems. Simulations are used as research tools to establish trends, demonstrate relationships between system parameters or make predictions about the future.
2. **Design**
   Designers use simulations to characterise or visualise a system that does not yet exist so as to achieve an optimum solution. For example, using simulation to model a manufacturing facility to experiment with layout of different capacity machines and storage bins, times for preparation and transfer of materials, so as to improve efficiency.
3. **Analysis**
   Analysis refers to the process whereby simulation is used to determine the behaviour or capability of a system currently in operation or to verify its correctness. It may also be used to test real life systems under extreme or even impossible conditions. Model behaviour is established by collection of data from the system. E.g. optimising the management of a hospital, by simulating the scheduling of doctors, staff, equipment and patients.
4. **Training**
   Training simulations are used to recreate situations people face on the job and to allow trainees to practice a sequence of actions or to learn the correct response to an event. Training can allow learners to make potentially fatal mistakes without injury. A great range of training can be carried out using simulations, from the highly complex which uses bespoke hardware (e.g. flight simulators, or mock-ups of nuclear power plants) to the simpler training available on a desktop PC (e.g. IT or soft skills training).
5. **Education**
   In education, learners don't just need to know "how" to do something; they need to know "why". Simulations represent an exploratory world where students can use models to conduct experimentation, to create and test hypotheses and construct their own understanding of a system. Simulations can provide tools for teachers to demonstrate and explain the behaviour of complex and dynamic systems. Potentially any simulation can be used in education at one level or another.

6. **Entertainment**
   Computer entertainment such as arcade games, war games, and role-playing games require a consistent model of an imaginary world. Many make use of simulation techniques used in training, design and analysis (for example for optimisation and control). Strategy games often contain sophisticated computer models e.g. SimCity.

4.2 Simulations plus other ingredients

Computer simulations are increasingly being combined with other ingredients to enhance the user's experience and provide greater realism, particularly in training and entertainment.

- **Simulations + humans.** The popularity of multi-player Internet games (e.g. Role playing games or simulated combat) is growing. Here humans take on roles and make decisions that might otherwise be made by the computer. In training, role-playing is suited to development of soft skills.
- **Simulations + other hardware.** Use of additional hardware is common in games arcades and increasingly in the domestic entertainment market. Some forms of virtual reality (VR) require sophisticated hardware. (N.B. Not all VR is simulation-based – see section 5.3)

5 The boundaries of simulation

There are a number of common misconceptions regarding what is and is not a simulation. This section looks at emulation, animation and virtual and augmented reality and discusses their relationship to simulation.

5.1 Emulation

Whereas the dictionary definition of simulation emphasises mimicry, that of emulation emphasises sameness and equality. The emulation attempts to be an exact copy of what is being emulated and not a model. Thus the definition in the Harcourt, Academic Press Dictionary of Science and Technology

*"**1.** the imitation of one computer system by another so that each can accept the same data or programs and produce the same results. **2.** the use of a program to simulate functions of hardware or another program."*

The output from an emulator is indistinguishable from the original, unlike a simulation. Typical examples are emulators of computer ROMs allowing legacy programs to run on modern hardware.

In a way, an emulator could be seen as an accurate simulation where no approximation has taken place and all features of the original are present in the emulation.

5.2 Animation

An animation is a series of moving images or a dynamic visualisation. An animation can be used to represent output from a system and can thus easily be confused with a simulation. What distinguishes an animation from a simulation is that it does not meet one or both of the key features of a simulation:

1. **There is a no model of a real or theoretical system behind the animation**. In this case, the animation is more like a cartoon, it will not be accurate as the speed and location of images is not calculated by a model. The animation cannot be altered to reflect a change in system conditions, only responds to preset values.

2. **There is no possibility of experimentation**: According to Laurillard, there has been terminological confusion when `simulation` is used to refer to a program that runs a model without any input from the user – the program generates its own input to the model, the user simply watches. This is certainly a simulation, but Laurillard contends that since the usual usage within education is "interactive simulation", it is reasonable to reserve the term simulation for those, and to relegate the non- interactive ones to the term "animation" or "demonstration" as they could equally well be shown on the non-interactive medium of video.

When the full capabilities of a simulation are not used, then it is possible to turn a simulation into an animation or even the equivalent of a video.

5.3 Virtual reality

Virtual reality (VR) is the provision of a real or imagined environment that can be experienced visually in the three dimensions of width, height, and depth and that may additionally provide an interactive experience visually in full real-time motion with sound and possibly with tactile and other forms of feedback. The applications developed for Virtual Reality cover a wide spectrum, from games to architectural and business planning. The virtual world may be a CAD model, a scientific simulation, or a view into a database. The user can interact with the world and directly manipulate objects within the world. Some worlds are controlled by other processes, such as physical simulations, or simple animation scripts.

The simplest form of virtual reality is a 3-D image that can be explored interactively at a personal computer, usually by manipulating keys or the mouse so that the content of the image moves in some direction or zooms in or out. As the images become larger and interactive controls more complex, the perception of "reality" increases. More sophisticated efforts involve such approaches as wrap-around display screens, actual rooms augmented with wearable computers, Head Mounted Displays (HMD) and haptic joystick devices that allow the user to feel the display images, providing what is known as immersive VR.

Some VR does include simulations but the simpler type such as wire frame and 3D models do not. The "model" in a simple 3D model, is spatial only, it does not include behaviour, and it doesn't react to perturbations. The changing view on the screen may appear to the user as changing output of the model, but it is merely a different view of a static model as the user changes viewing angle. Such VR is not simulation according to the definition used in this paper, as the model does not include behaviour.

5.4 Augmented reality

Augmented Reality (AR) is a growing area in virtual reality research. The real world provides information that is difficult to duplicate in a computer. An augmented reality system generates a composite view for the user. It is a combination of the real scene viewed by the user and a virtual scene generated by the computer that augments the scene with additional information.

A typical example of use would be by a contractor laying pipes underneath a road. A Head Up Display (HUD) would recognise the user's location and overlay the location of cables and pipes so the operator can avoid hitting objects underground. The data overlaid on a real world view is unchanging, but the user's view of that data changes as the user's position changes. This is not a simulation, but a sophisticated data display.

5.5 Viewing models with no behaviour.

In the sections on VR and AR it was noted that the ability to change a viewpoint into a static dataset or model with no behaviour, did not constitute a simulation, as there was effectively no change of model state.

There is in fact a whole group of software applications that are models with no behaviour that are effectively inanimate♣. The more sophisticated of these models are sometimes mistaken for simulations, but essentially, they are no different to the simplest sort of inanimate model, a set of linked html pages in a document where:

- the "model" is the web pages and inbuilt navigation;
- the input is the user's choice of navigation option;
- the output a new view of the document i.e. a different page .

Information and data held in the "inanimate model" is static and unchanging; the user can change the view of the model or data but not change the actual data. The same is true of a set of interfaces whose navigation is controlled by flowchart where the user is navigating through a predefined structure. There is a class of software, some quite sophisticated that is not a simulation but is a viewer of a fixed model or dataset whose value does not change. The term data "Model viewer" is introduced to cover this type of software.

Understanding the difference between navigation through a predefined structure in an inanimate model and the possibility of open exploration within a true simulation is crucial to grasping the potential of using simulations in education.

5.6 The relationship between simulation and simulation-like software

The relationship of the software types discussed in this section and simulations in general is shown in the chart in Figure 2. The Y-axis is "complexity of model" this is

♣ The term "inanimate models" will be used to cover this form of model.

effectively a measure of the number of input variables that affect the model behaviour.

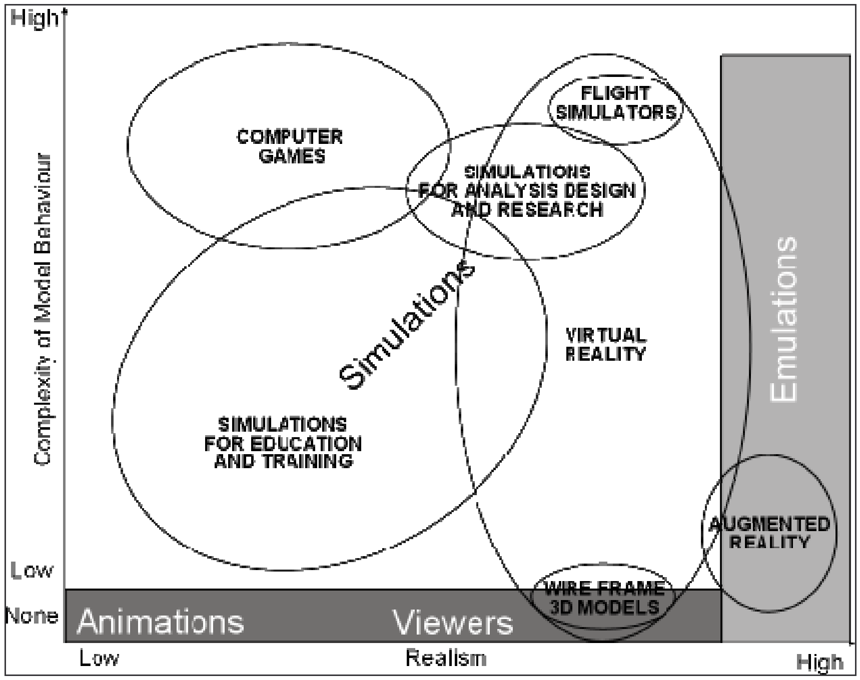

Figure 2 *Relationship of simulations to emulations and viewers*

The x-axis relates to "realism". Approximations and simplifications are made during model production. Greater simplification leads to reduced realism.

Simulations cover the primary area (white) of the chart. Related activities fall on the periphery outside the boundary. Thus an animation with no model behaviour and which is not representative of reality falls in the bottom left. "Model viewers" provide access to data that may be highly realistic, but as they exhibit no behaviour, their location falls along the base of the graph. Emulations that accurately reflect reality and have a range of complexities of model fall on the extreme right of the graph.

The general locations of other software mentioned in this paper are also shown as ellipses. Note these groupings are indicative only and are designed to show the area where most items of that type fall.

Within the simulation space there are a number of general trends that can be identified, these are shown in figure 3.

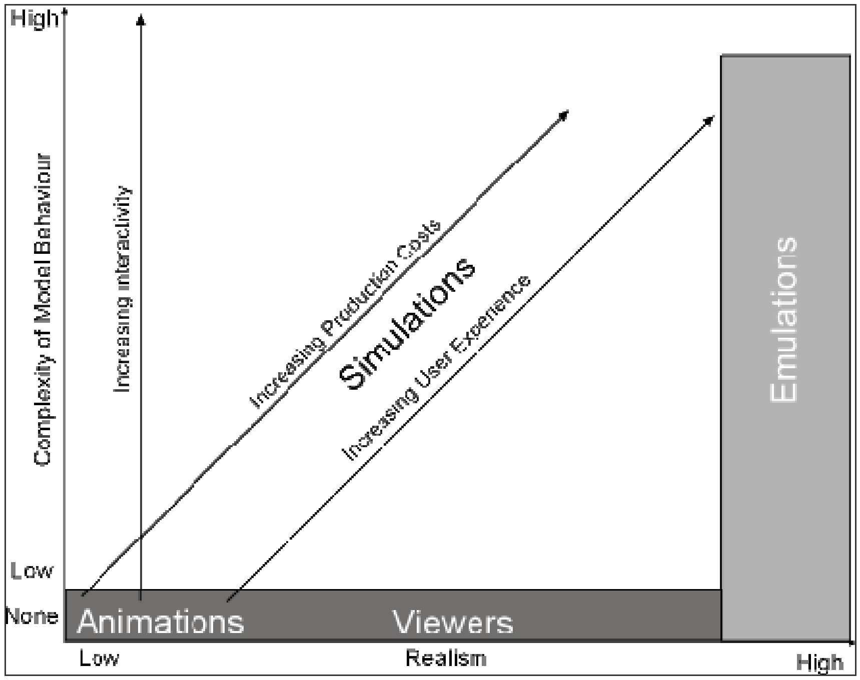

Figure 3 *Trends within simulation space*

6 Changes to the scope of the term "simulation"

With the advent of the Internet and the growth of e-Learning and the widespread availability of CBT and the recognition that interactivity and "learning by doing" is important in providing good quality material, the term simulations has positive overtones and the benefits of labelling courseware as simulation is obvious. This is leading to a looser application of the term, simulation. A typical example is in a report published by brandon-hall.com[3]:

> *"In eLearning simulations strive to recreate the students work environment. Since context and practice are two keys in retaining and applying knowledge simulation provides the means for the student to have hands on experience without the costs or risks involved in working in the live environment."*

The definition is from a training perspective and in the survey, simulations are grouped into 6 main categories. A review of these categories shows that only 3 of the 6 completely fit the criteria used for simulations in this paper. The categories are show on the plot in Figure 4. The numbers used for each type of simulation are as used in the list below.

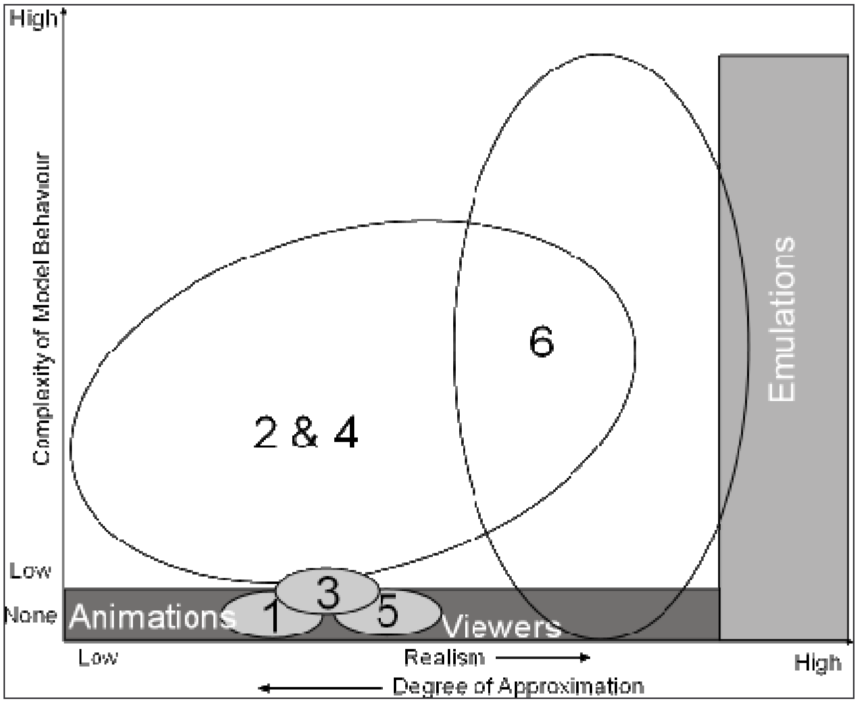

Figure 4 Simulation *space occupied by Brandon Hall simulation categories*

1. **"Software simulations"**: Simulating a software application in order to train users in basic functionality of a software application. This can range from replay of screens in the application without interaction to more interactivity and assessment. **Verdict**: This isn't a simulation, but a combination of animation or model viewer. There no possibility of changing the model or deviating from preset routes through the material.
2. **"Business simulations":** This class of software involves the simulation of business processes for instance to allow employees to understand the dilemmas involved in running a company. It involves a model that can be manipulated to see the outcome of decisions.
   Verdict: Simulation - there is a model with behaviour and experimentation is possible.
3. **"Situational simulations":** These include role-playing and case-based scenarios, which are typically developed to assist learners in problem solving, usually in the business and soft skills area. Learners are typically members of the environment in these simulations rather than being some external force that manipulates variables at will. Feedback in the form of a costs incurred or time elapsed may be provided. These types of simulations are often produced using standard authoring tools linked to "state tables" or flowcharts mapping different paths through the role-play scenario.
   Verdict: May or may not be a simulation. If this software is a series of preset steps with a choice of routes that the user navigates then this form of software is not a simulation. If however, the user can make a make a mistake and for example incur greater costs as a result then it would constitute a simulation.
4. **Technical simulations:** This grouping includes flight simulators, process simulators or time-based scenarios. These map closely to the true simulators discussed earlier in this paper.

Verdict: Simulation - there is a model with behaviour and experimentation is possible.

5. **Procedural simulations** (task simulators): These allow learners to perform steps in a simulated environment to learn procedures (drill and practice). There is some overlap between procedural and software simulations, because many of the software simulations are based on performing tasks in sequence.
   Verdict: In terms of models, these have some similarity to "situational" simulations in that a flowchart of actions is provided and in the same way procedures can be timed or scored and easily turned into competitive games that brings them closer to simulations.
6. **Virtual worlds:** Recreating images and appearance of reality. 3d and wire frame models come under this category**.**
   Verdict: Usually, as has been shown, these types of virtual reality are not simulations unless the model exhibits some form of behaviour**.**

The meaning of the term simulation is being distorted by over use. As a partnership focussed on simulations, JeLSIM can clearly identify the area of the simulation world it occupies.

7 The e-Sim

JeLSIM eSims occupy the area shown in Figure 5.

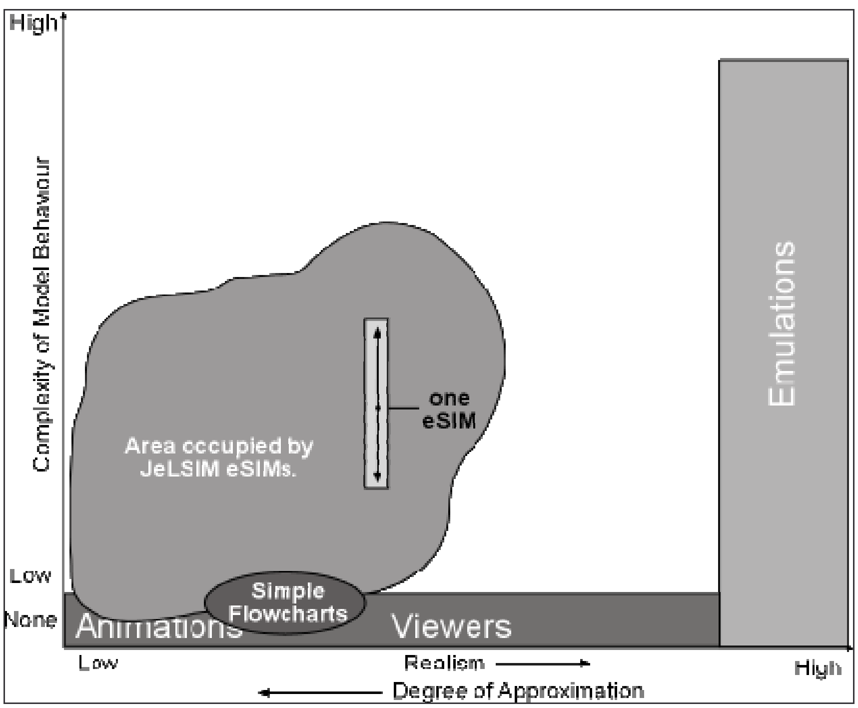

Figure 5 *The simulation space occupied by JeLSIM eSims*

Simple models with analytic solutions fall at the bottom left of the chart with more complex higher and to the right. Generally speaking, models for educational purposes are simpler than those used in analysis and design and so fall in the lower left quadrant of the chart. A single JeLSIM model, can be presented with many different interfaces of differing complexity so unlike other applications that occupy a point on the chart, can occupy an area of the graph.

8 Conclusion

To be a simulation, software must meet 2 criteria:

1. **There is a computer model of a real or theoretical system that contains information on how the system behaves.**
2. **Experimentation can take place. i.e. changing the input to the model affects the output.**

There is a range of software described as simulation that is not simulation. The educational benefits of using simulation come from the ability to learn by doing and exploration. It is only possible to conduct an experiment within a simulation if the model has a defined behaviour. Inanimate models frequently confused with true simulations do not have this capability. Understanding the difference between simulation and simulation-like behaviour is all important as we look at the educational potential of simulations in paper 2.

9 References

[1] Fishwick, Paul A., (1995), "Simulation Model Design and Execution". Prentice Hall Inc.

[2] Laurillard, Diana, (1993) , "Rethinking University Teaching a framework for effective use of educational technology". Routledge.

[3] E-learning simulations: Tools and Services for Creating Software, Business and Technical Skills simulations. (March 2002). See: http://www.brandon-hall.com/simulations.html for details