Yearwood, J., & Stranieri, A. (2007). Narrative-based Interactive Learning Environments from Modelling Reasoning. *Educational Technology & Society*, 10 (3), 192-208.

Narrative-based Interactive Learning Environments from Modelling Reasoning

John Yearwood and Andrew Stranieri
School of Information Technology and Mathematical Sciences, University of Ballarat, Victoria, Australia
j.yearwood@ballarat.edu.au

ABSTRACT
Narrative and story telling has a long history of use in structuring, organising and communicating human experience. This paper describes a narrative based interactive intelligent learning environment which aims to elucidate practical reasoning using interactive emergent narratives that can be used in training novices in decision making. Its design is based on an approach to generating narrative from knowledge that has been modelled in specific decision/reasoning domains. The approach uses a narrative model that is guided partially by inference and contextual information contained in the particular knowledge representation used, the Generic/Actual argument model of structured reasoning. The approach is described with examples in the area of critical care nursing training and positive learning outcomes are reported.

Keywords
Narrative, interactive learning, case-based learning, decision making, emergent narrative, transformationalism

Introduction

There are two main approaches that people use to organize and make sense of their experiences: logical thinking and narrative thinking. Both of these approaches have a long history of providing useful structures for organizing experiences. Narrative reasoning can provide a valuable approach to complex reasoning involved in problem solving and decision-making. Often, clear practical reasoning towards decisions is required in an area, though the area may be poorly understood and not amenable to learning by some form of logical analysis and representation.

Setting out the reasoning involved in certain situations may improve transparency but does not in itself add to the understanding or absorption by the practitioner. Presenting this reasoning as narrative scenarios provides a means for practitioners to assimilate the reasoning above abstract rules and has the potential to connect with human understanding at the story level. Stories have been shown to be useful for clarifying uncertainties and problem solving (Hernandez-Serrano & Jonassen, 2003). This resonates with the notion that Schank had about human reasoning described in Schank (1990), that people do not naturally reason deductively, but rather use a form of thinking that might be called "story-based reasoning". We can draw on our own experience to notice that most communication between people could be characterised as having a story form. These “mini-stories” correspond in workplaces and technical contexts to scenarios. In the legal context, Pennington & Hastie (1981) have demonstrated that jurors display narrative and not just logical reasoning to make sense of evidence.

Pennington and Hastie's story model is based on the hypothesis that jurors impose a narrative story organization on trial information, in which causal and intentional relations between events are central (Pennington & Hastie, 1981). Meaning is assigned to trial evidence through the incorporation of that evidence in one or more stories describing what happened. Pennington and Hastie demonstrated the influence of story order on verdicts in criminal trials. They found that if a party's story was told to the juror in story order instead of in a random order, such as the witness order, the juror more easily followed that party's story in the verdict. If the prosecution's case was told in story order, while the defendant's case was told in a random order, the accused was convicted in 78% of the cases. If, on the other hand, the prosecution's case was relayed in random order and the defendant's in story order, the accused was convicted in 31% of the cases. This work strongly suggests that narrative organization of material can have a significant impact on the way it is understood and used to come to conclusions.

As we move towards a knowledge-based society and knowledge is increasingly represented for use within computational systems it is important to be able to develop efficient ways of using that knowledge effectively for training. An environment that allows the interactive construction and manipulation of narratives that correspond to practical reasoning instances would provide a useful platform for interaction and learning. Furthermore if the narratives are underpinned by the desired reasoning model then the environment can have the capacity to flexibly involve participants in their learning.

In this paper we describe a narrative-based Intelligent Interactive Learning Environment (IILE). Through interaction with the IILE, learners are allowed to engage with the tasks that they may be called upon to perform and the decisions that they will need to make. Presenting this knowledge as a set of graphs and argument trees is not very useful to a learner, although it does have value in its visual representation. Group discussion of these graphs has also proven to be useful in reinforcing tradition methods of communicating the knowledge. There are three important aspects to the narrative based-IILE:

- Its intelligence is based on the expert knowledge modelled in a knowledge acquisition exercise;
- the knowledge is used to generate narrative that express practical reasoning situations;
- user interaction is based on the learner interrogating or acting in the environment and the system providing response through narrative description and advice that is constructed for dramatic effect.

In the next section, we describe the motivation for this work and then survey literature on narrative in order to motivate the story framework deployed in the IILE. Following that, the Generic Actual Argument Model (GAAM), the model of reasoning that is used in the IILE to infer whether the actions taken by the protagonist are correct, and if not, which events should occur to heighten the consequence of the error, is described. In section five, a detailed example is provided before concluding remarks.

Motivation for a Narrative-based IILE

In our work with a range of decision makers involved with complex decisions it has been found that there is an expressed need for a representation of reasoning in the form of scenarios or small stories. Whilst there have been advantages of presenting reasoning as *structured reasoning* (Yearwood & Stranieri, 2006), there seem to be further advantages in annotating reasoning structures within a domain with narrative in the form of scenarios. Geoffrey (2005), in research on clinical reasoning and expertise points out that the nature of expertise lies in the availability of multiple representations of knowledge and that in terms of learning reasoning "…the critical element may be deliberate practice with multiple examples which, on the one hand, facilitates the availability of concepts and conceptual knowledge (i.e. transfer) and, on the other hand, adds to a storehouse of already solved problems."

Case-based learning has been employed in law schools since the 1800's. In general, students are presented with a story or narrative of events and this is either read or `acted' by students, leading them to a `correct' response or to understand the effects of their decisions. Cases have been prominent in teaching about roles in which decisions have to be made and are less likely to be used in school situations (Merseth, 1991). Amongst some of the features of a `good' case, Herreid (1998) mentioned that a good case:

- *tells a story* - have an interesting plot that relates to the experiences of the audience and have a beginning, a middle, and an end.
- *focuses on an interest-arousing issue* - there should be drama and a case must have an issue.
- *should create empathy with the central characters.*
- *should have pedagogic utility.*
- *is conflict provoking.*
- *is decision forcing.*
- *has generality***.**

Jarz et al. (1997), in developing multimedia-based case studies in education point out the need for didactic design, the need to collect, reduce and structure data for the construction of the case.

An IILE that allows a user (learner) to interact in constructing narratives that correspond to the use of domain reasoning to solve problems contains elements of Schank's goal-based scenarios (Schank, 1996) and anchored instruction (Cognition and Technology Group at Vanderbilt, 1990). The benefits of using cases and stories for instruction have been demonstrated in many studies (Bransford & Vye, 1989; Bransford, Sherwood, Hesselbring, Kinzer & Williams, 1990). Hung, Tan, Cheung and Hu (2004) discussed possible frameworks and design principles of good case stories and narratives. Narrative is a fundamental structure of human meaning making (Bruner 1986; Polkinghorne 1988). Stories are effective as educational tools because they are believable, easily rememberable, and entertaining (Neuhauser 1993). The believability derives from their dealing with human experience that is perceived as authentic. They aid remembering because they involve an audience in the actions and intentions of the characters. As audience, we are engaged with the story on both an action level and a consciousness level and it is through this dual engagement that we become involved with the minds of the characters and understand the story.

When narratives are underpinned with sound domain knowledge, they can provide a way of assimilating and realizing practical reasoning in an effective way. In specialised fields like health (e.g. intensive care nursing), learners already have significant basic knowledge and training. The pedagogy that is appropriate in these circumstances tends not to be that for understanding basic knowledge in the discipline, or that for studying clinical problems in the abstract but needs to be appropriate for the gaining of expert knowledge. Evidence indicates that this is achieved through induction from cases. Frize & Frasson (2000) distinguish three levels of cognitive learning styles that are evident in medical schools. Figure 1 indicates the different pedagogies that are appropriate for different learning contexts.

Problem based learning has been widely adopted in both medicine and law. According to Mayo, Donnelly, Nash, & Schwartz (1993)`problem-based learning is a strategy for posing significant, contextualized, real world situations, and providing resources, guidance, and instruction to learners as they develop content knowledge and problem-solving skills'. The amount of direct instruction is reduced in problem based learning, so students assume greater responsibility for their own learning. The instructor's role becomes one of subject matter expert, resource guide, and task group consultant. Many medical schools use a problem based learning methodology to teach students about clinical cases, either real or hypothetical (Vernon & Blake, 1993).

At the beginning of their curriculum, students learn basic knowledge to build a base of fundamental knowledge. During this period this knowledge is stored and not yet linked to real cases. This is the first level shown in Figure 1. The student is only able to identify basic problems, and generate basic solutions. In progressing to clinical problems, the second level shown in Figure 1, students acquire some procedural and contextual knowledge, a step in which elements of knowledge are linked through examples of situations. They make hypotheses and start to establish strategies for selection and rejection of these. Problem-based learning is appropriate and often used to support this activity.

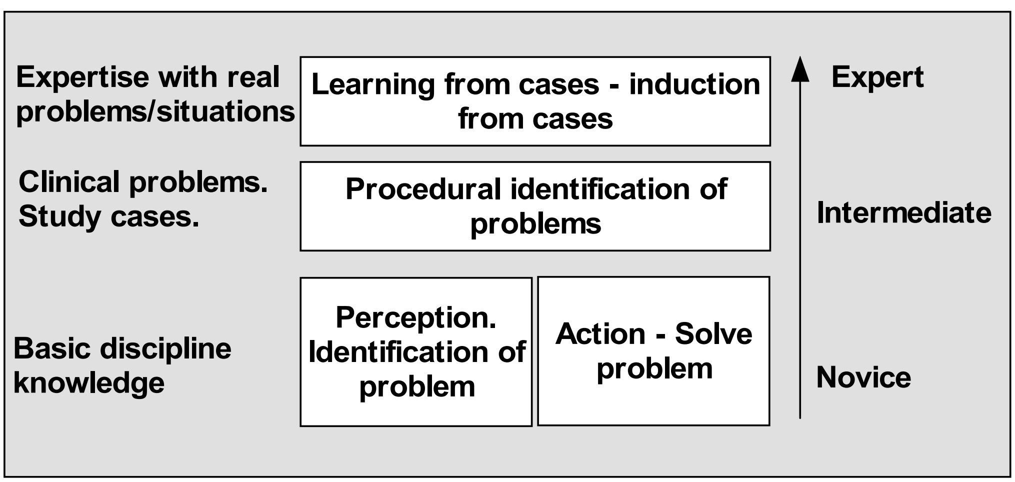

Figure 1: Frize & Frasson's pedagogical approaches for different learning levels

The top layer of Figure 1 is concerned with acquiring knowledge through exposure and interaction with real situations or cases. The learner can accumulate experience with a more complete base of cases and may reach expert status by being able to induce new rules or new cases from a set of cases. The cognitive model operating here being case-based reasoning. Becoming an expert is usually associated with active exposure to many real cases. The transformation from the second level to the upper, expert level is achieved through experience with complex real cases. This fits within the framework of transformationalism (Mezirow, 2000) and in most situations the transformation from novice to expert will be incremental. Mezirow also suggests that transformation can be triggered by narrative that relates to the learner's own experience.

Problem based learning is a strategy that motivated the design of the intelligent learning environment (IILE) described in this paper. Exposure to real-life problems in an interactive simulation of the real situation is targeted at facilitating the transition from novice to expert. However, given that narrative plays such an important role in human learning, an IILE based on narrative structures is likely to enhance the learning. Narrative based interactive learning environments have been advanced by Peinado, Gervais and Moreno-Ger (2005), Iuppa et al. (2004), Riedl and Young (2004) and Cavazza, Charles and Mead (2002). Narrative based environments deploy similar ideas to those described by Schank (1996) and anchored instruction (Cognition and Technology Group at Vanderbilt, 1990).

In the majority of narrative based interactive learning environments multiple storylines are stored in the environment in one way or another. For example, the branching decision tree structure used by Iuppa et al. (2004) encodes multiple pre-authored plans into a single decision tree. A learner interacts with the system by selecting events that branch the storyline in different ways. The control a learner has to shape the direction of the story enhances his or her engagement with the situation and leads to a deeper engagement with the material to be learnt.

According to Peinado, Gervais and Moreno-Ger (2005), IILE architecture based on pre-authored cases conflicts directly with the learner's desire to exercise free will. A learner exercises no free will in the construction of a case study presented in a text or classroom situation, and only slightly more free will in selecting branches from a tree of storylines. In order to enable learners to exercise more free will and therefore engage more fully with the learning environment, Peinado, Gervais and Moreno-Ger (2005) have devised an IILE that allow the learner to perform actions at will. Their IILE matches a learner's actions against set storylines. If the learner deviates from a set storyline, the system generates a new storyline that will, as far as possible, realise the objectives of the original learning plan. This is achieved with the case based reasoning paradigm. Cases are encoded as story plots and case adaptation is used to generate new storylines.

In this paper we describe an IILE that similarly allows the learner substantial freedom. The IILE presented here is underpinned by two pillars:

- a strong model of expert reasoning in the subject matter domain. A strong model of expert reasoning is provided by a knowledge representation model called the Generic Actual Argument model advanced by Yearwood and Stranieri (2006) deployed in numerous knowledge based systems to date including *Nurse*, a system that depicts steps of best practice for critical care nurses to take when responding to a low oxygen alarm in a ventilated patient.
- a connection of the reasoning model to a narrative structure in a way that allows emergent narrative from learner interaction. The narrative structure is based on the model described by Bennett and Feldman (1981). The IILE reflects the emergent narrative as a 'story so far' feature that acts as the voice of a third person narrator articulating the emergent narrative as feedback to the learner.

The approach advanced here is most appropriate in disciplines where reasoning is intricate and usually not set out as rules. It may be set out as guidelines, have a large tacit component or learned through on-the-job training. In these areas, simply acquiring a model of the reasoning and presenting it as rules or instructions does not seem to add to the understanding of the area to elevate a novice to expert.

Rather than hard coding multiple storylines in a memory, the IILE presented here begins a narrative and then enables a learner to perform actions on the patient. The IILE uses a strong domain model to infer whether the actions are appropriate and if not, to identify the consequences of the error. Consequences are used by the IILE to set events that will propel the emergent narrative towards critical outcomes such as patient death. The IILE does not present fixed narratives crafted from a real or hypothetical case but instead allows the learner to take a large role in constructing the narrative. The story that emerges from the interaction of the learner and the IILE is responsive to the learner's actions.

Narrative Reasoning

Much of our attempt to understand our world has taken the form of stories and narrative myths. These myths and stories have often passed on, in a compressed form reasoning that has been important practically as well as in a literary sense. McCloskey (1990) described stories and metaphors as the two ways of understanding things and suggests that they can work together to provide answers. Narrative reasoning addresses situations that find difficulty in being addressed with the sequential form of logical reasoning. The situations often involve multiple causes and multiple effects. Many social phenomena are like this and it would be fair to say that the great body of our accumulated social wisdom is expressed as narrative. Narrative reasoning could be viewed as an efficient way of dealing with complexity.

In both formal logical reasoning and narrative reasoning, cause and effect relations are established (Warren et al, 1979) between factors and used in sequential patterns. Both aim to organize and make sense of human experience in a way that can guide problem solving and decision-making. Whilst we recognize the product of logical or analytical reasoning as laws or rules which are largely context free and testable, the product of narrative reasoning is a story which is highly contextual and testable mainly through personal and interpersonal experience.

We view narrative as comprising two fundamental parts: story and discourse (Chatman 1990, Emmot 1999). From a narratological perspective, a story consists of a complete conceptualization of the world in which it is set and so includes all the characters, locations, actions and events that take place during the story. Two fundamental components of a narrative are its plot and its characters and these are defined within the story itself. The discourse contains those elements responsible for the telling of the story. The most important of these is the particular selection of the story elements that the narrator will use and the medium.

Most stories have a predictable structure or pattern of events that create the properties of a story and include *basic elements* and *abstract story structures*. Most narrative theorists agree that the basic elements of stories include *objects, events, causality* and *time.* A *character* is a type of object that has attributes, motivations and a spatial relationship with other objects. According to Black and Wilensky (1979) such a cluster of objects is usually called a *scene*. *Structures for characters* in stories depend on their role in the story. There are five basic roles (although other sets have been used): protagonist, antagonist, helper, hinderer and neutral. The protagonist is the main character and the antagonist is the main opponent of the main character.

Structures for events are classified in terms of their influence on objects and on the episode in which they occur. The influence that an event has is related to the number of objects that the event affects. An event which affects objects in many scenes is called a *global* event. The *episode* in which events occur refers to the sequence of events that occur in a particular scene. Structures for causality have generally been disregarded in non-computational models. In Schank's influential script model, causality has four types: result causation, enable causation, initiation causation and reason causation. Three *structures for time* are identified: story-time, discourse-time and iconographic-time. Story time is monotonically related to normal time whilst discourse time is the order in which events are presented to the audience. Iconographic time refers to the period in which the story is set.

While the basic elements are generally agreed upon, it is the abstract story structures that have provided the greatest area of debate. *Abstract story structures* refer to those structures that can be abstracted from stories but are not explicitly represented within stories. Many abstract structures have been proposed such as plots and episodes. *Top-down* approaches provide a framework that is filled in progressively as the story unfolds. *Bottom-up* approaches provide a number of units that are matched to elements of a story and are connected together to provide a representation of the story. *Event-scene* structures are those which relate the objects of a scene and can be classified as to whether events are dependent or independent of the scene. *Event-character* structures are those that relate to the interactions between events and characters. These can be classified as those which affect every character or those which affect the main character. Event character structures link specific events to characters' goals which in turn cause other events and outcomes for those events.

An *event-character* goal hierarchy structure views stories from the point of view of characters dealing with various types of conflict. Rumelhart (1975) exemplifies this approach in formalizing the work of Propp (1968). Episode schemas describe various events in every story in relation to a character's goals. Many event-character structures are variations of story grammars. Black and Wilensky (1979) criticize story grammars due to their inability to distinguish between stories and non-stories (e.g. procedural exposition). Criticism has also been levelled at the limited way in which these grammars represent stories as little more than a set of coherent sentences although Mandler and Johnson (1977) and Mandler (1984) have used a grammar that captures quite complex story structure.

Wilensky (1982) claimed that understanding a story is more about understanding the point of what the text is about rather than understanding the structure of a text. The notion of a story *point* competes with the idea of story grammars as a way to characterize story texts. In the *points* structure used in the story understanding program PAM (Wilensky, 1982) a story has three levels: the story itself; the important content of the story; and the points. The *points* are a template for the important content of the story in terms of the goals of the characters. A story grammar defines a story as having a certain form, whereas a story point model defines a story as having certain content. The form of a story is viewed as being a function of the content of the story.

The narrative theory of Bennett and Feldman (1981) describes the structure of a story as consisting generally of a *setting, concern, resolution* sequence. The setting usually includes the time, place and some of the characters. The concern is an action that given the setting creates a climactic (eventful, ironical, suspenseful) situation. For example, if someone is rock-climbing and slips and falls, slipping and falling are the concern. If the story ended at this point, the audience would be left wondering: what happened to the climber? Was he hurt or killed? A complete story will provide an answer to these questions. This stage is the resolution. The central action is the structural element that creates the central question the story must resolve. The resolution normally resolves both the predicament created by the problem and the questions listeners might have had about the outcome. In the rock-climbing story the resolution consisted of telling the audience that the climber was taken to the hospital for treatment.

Bennett and Feldman (1981) argue that it is not the weighting of the individual elements of the story, each in terms of the evidence for that element, which renders a case persuasive or not, but rather the plausibility of the story structure taken as a whole. In a good story all elements are connected to a central action and nothing is left standing on its own. The context provides a full and compelling account of why the central action should have developed in the way that it has. If this is not the case then the story contains ambiguities.

Wagenaar et al. (1993) proposed the theory of anchored narratives moving on from the work of Bennett and Feldman (1981) where the task of the judge was seen as determining the *plausability* of the stories presented by the prosecution and the defence. This narrative theory has its basis in cognitive psychology and contends that evidence derives its meaning from a story context. The plausibility of the story is related to its *narrative coherence*. Various schema-based approaches have been used in the study of story understanding. Story grammars try to capture and define the internal structure of stories as grammars. Many story grammars have been proposed and studied (Mandler & Johnson, 1977; Rumelhart, 1975; Simmons & Correira 1979; Thorndyke, 1977). Frames could be used to represent stories with slots for setting, protagonist, main event, moral or point, characters. However, progression through the story may need modification. The main way in which frames have been used in story modelling is as scripts. A script is a predetermined, stereotyped sequence of actions that defines a well known situation (Schank & Abelson 1977). They do not have the capacity to deal with unfamiliar and novel situations which is important in stories. SAM (Script Applier Mechanism) is a program that `understands' stories that are heavily based on scripts. Plans (Schank & Abelson 1977) can be used to tackle the problem of dealing with tasks for which there is no script. PAM is a program that understands plan-based stories.

The *setting, concern, resolution* sequence of Bennett and Feldman (1981) is well suited to the IILE in this work. The rich domain model deployed in the IILE is sufficiently expressive to obviate the need to embed structures to represent causal relations between elements found in more complex story grammars. A relatively simple story grammar is sufficient because the domain model is so expressive. The domain model deployed is based on argument structures and is described in the next section.

Representation of Domain Reasoning

An approach for representing knowledge called the Generic Actual/Argument Model (GAAM) has been advanced by Yearwood and Stranieri (2006). The GAAM model has been applied to the development of numerous decision support systems in law including; *Split Up,* predicting the percentage split of assets a Family Court judge awards divorcees (Stranieri et al., 1999), *Embrace*, assessing the strength of claims for refugee status (Yearwood and Stranieri, 1999), *GetAid,* determining eligibility for legal aid in Victoria (Stranieri et al., 2001) and witness selection in Scotland (Bromby and Hall, 2002). A web-based engine developed to implement the GAAM (*justReason* http://www.justsys.com.au) automatically generates a web based decision support system accessible with any web browser, using the knowledge.

The GAAM represents reasoning to a decision at two levels of abstraction, the generic argument level and the actual argument level. A generic tree that captures reasoning regarding risks associated with roof light design is illustrated in Figure 2. The 'root' of the tree is the OHS risk rating associated with a particular roof light element in a building. The linguistic variables "extreme", "high", "moderate" and "low" represent acceptable terminology for denoting the magnitude of risk in that field.

Every variable in a generic argument tree has a reason depicting its relevance. The factors *likelihood that an injury or illness will occur*; and the *likely severity of the consequence of that injury or illness should it occur* are relevant because risk management theory and Australian legislation dictates these two factors are relevant for determining risk. Argument trees are intended to capture a shared understanding of relevant factors in the determination of a value (in this case the level of OHS risk). Irrelevant factors are not included in an argument tree. Thus, the roof light colour is not considered relevant by designers or safety experts, so is not represented as a node in the tree - though one can imagine circumstances where a colour is indeed relevant to OHS, such as in the specification of emergency lighting or signage.

An actual argument is an instantiation of variables in the generic tree by setting leaf node values and inferring up the tree. A linguistic variable value on a parent node is inferred from values on children nodes with the use of inference procedures. An inference procedure is essentially a mapping of child variable values to parent variable values. In Figure 2, the inference procedures are denoted by A, B, C, D and R. Thus, for example the inference procedure R could take the form of a commonly used risk matrix where assessments of likelihood and consequence combine to determine the level of risk presented by a hazard. Thus a hazard for which the likelihood of occurrence is rated moderate but the consequence is major would be considered "Extreme."

For example, the risk rating is inferred using an inference procedure, R from values instantiated on two factors: In Australia, the inference derives from a risk matrix formula set by a government based standards organisation. The height and location of a roof light are factors that lead to an inference describing the consequence of a fall (i.e. the severity of the injury). The trolley system and protection for external work are used to infer an overall level of protection, and therefore the likelihood that a fall will occur. The existing protection is also coupled with the frequency with which the roof light will be maintained to infer the likelihood of a fall.

In argumentation-based KBSs different inference mechanisms can be used according to the nature of knowledge being modelled. For example, in the 'Split Up'system (described in Stranieri et al., 1999), neural networks trained on data drawn from divorce property judgements were used to infer about half of the 35 nodes. In a different system, known as 'Embrace,' which supported the determination of someone's refugee status, inferences were always left to the discretion of the decision-maker (Yearwood and Stranieri, 1999). In another system called GetAid, Stranieri et al. (2001) assigned weights to each linguistic variable and then summed these weights before and compared the result with a pre-determined threshold to infer eligibility for legal aid.

Argument trees, such as that depicted in Figure 2, represent a template for reasoning in complex situations. Thus, in a discussion about the level of risk posed by a particular roof light, two designers might disagree at the root node level in that one designer perceives the risk to be high while the other perceives it to be moderate. This difference in perception may derive from the different values assigned by each designer to subordinate nodes in the argument tree. For example, when one designer believes that existing protection is certainly adequate, whereas the other does not. The difference may also derive from alternate inference procedures; one uses inference A, the other uses a different mapping mechanism. However, although the two designers disagree, they can both reasonably accept the argument tree structure as a valid template for the expression of their beliefs.

The generic argument level is very useful in determining the mapping to the narrative model because it is rich in contextual information as well as providing information on reasons for relevance of premises (which ensures coherence) and reasons for inference procedures which captures values and principles behind the reasoning as well as sequencing information for events when their order is critical to the reasoning.

Table 1 illustrates the elements of the GAAM and the corresponding story elements that comprise the structured reasoning to narrative mapping central to the IILE.

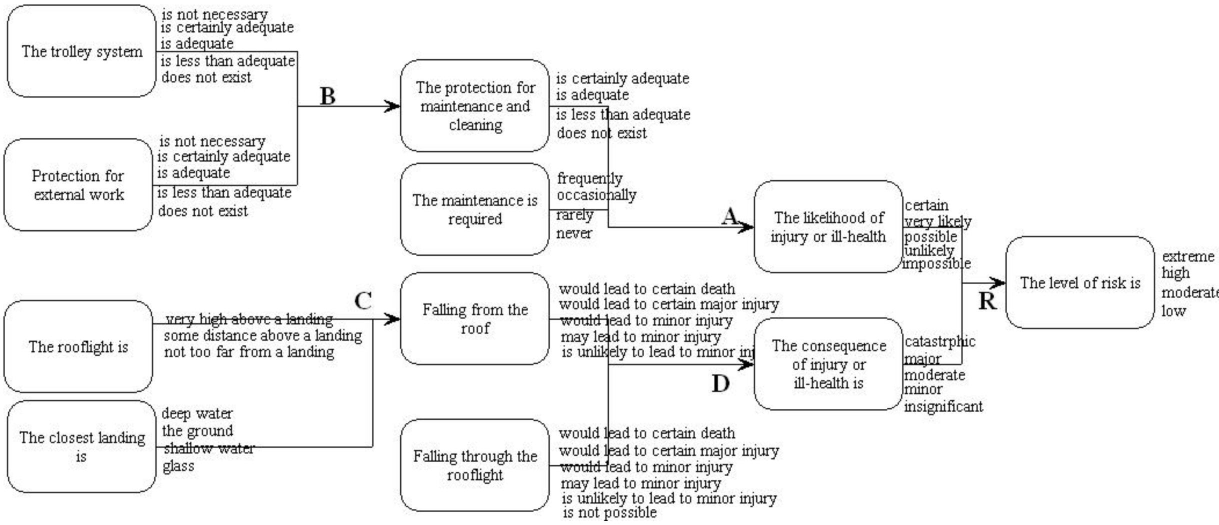

Figure 2: The structure of an argument tree in occupational health and safety

The mapping of the GAAM to story elements provides the framework for the IILE. In the next section an example from the domain of critical care nursing is provided that illustrates the mechanisms in some detail.

Table 1: Mapping of GAAM to Story elements

Reasoning: GAAM Element	**Story Element**
Context variable values	**Setting**
Not represented	Character
Set of child factor values, e. g. The likelihood of injury is *certain.* The consequence of injury *is catastrophic.*	**Concern**. Our protagonist will be exposed to certain catastrophic injury
Inference procedure reason, e. g. The risk matrix, R in Figure 2	Point. Protagonists exposed to certain catastrophic injury is at extreme risk
Parent factor value, e. g. The level of risk is *low*	**Resolution**
Not represented	Narrative voice
Reason for relevance of child factors	Coherence

Extended Example

Advances in critical care technologies and practices over recent decades have led to decision making settings that are complex and demand extensive nursing training. Monitoring and responding to ventilated patients' gaseous exchange is a central role for ICU nurses. (Van Horn, 1986) argued that there are too many factors or possible solutions for a human to remember at once, even when the problem is broken down into smaller pieces. Decisions must be made under pressure, and missing even a single factor could be disastrous.

The decision making involved in determining the actions a nurse should perform when a low oxygen alarm sounds with a mechanically ventilated patient is typically taught informally 'on the job' in conjunction with some classroom exercises. In practice, nurse educators aim to instil knowledge of three aspects of practical reasoning to novices:

- *Action* - What action to perform next. For example an action an ICU nurse has to learn to perform is to check the shape of the pleth wave. This is a wave displayed on a monitor that is derived from an infrared finger probe detecting the level of oxygen in the blood stream.
- *Incorrect Action Consequence* – This is the consequence of performing the incorrect action. For example, changing the finger probe is the correct action when the oxygen alarm is sounding and the pleth wave is noisy. A noisy pleth wave often indicates the probe is not reading accurately. Checking the blood pressure at this time has a consequence that is relatively minor in that it diverts the nurse's attention from effective troubleshooting.

Other situations have more serious consequences. The severity of each consequence is captured on a scale from 1-10 illustrated in brackets in Figure 3.

- *Omission consequence* – This is the immediate consequence of failing to perform the action when it is should be performed. Failing to administer pure oxygen to the patient when the alarm has sounded and the pleth wave is accurate results in a possible state of insufficient oxygen.

Reasoning involving the action and consequences following a low oxygen alarm in an Australian hospital has been modelled using decision trees described in Stranieri et al. (2004). In that study, reasoning was modelled using a decision tree in order to implement a decision support system that represented best practice in critical care nursing. The decision tree structure has been converted to an argument tree representation shown in Figure 3 for the IILE.

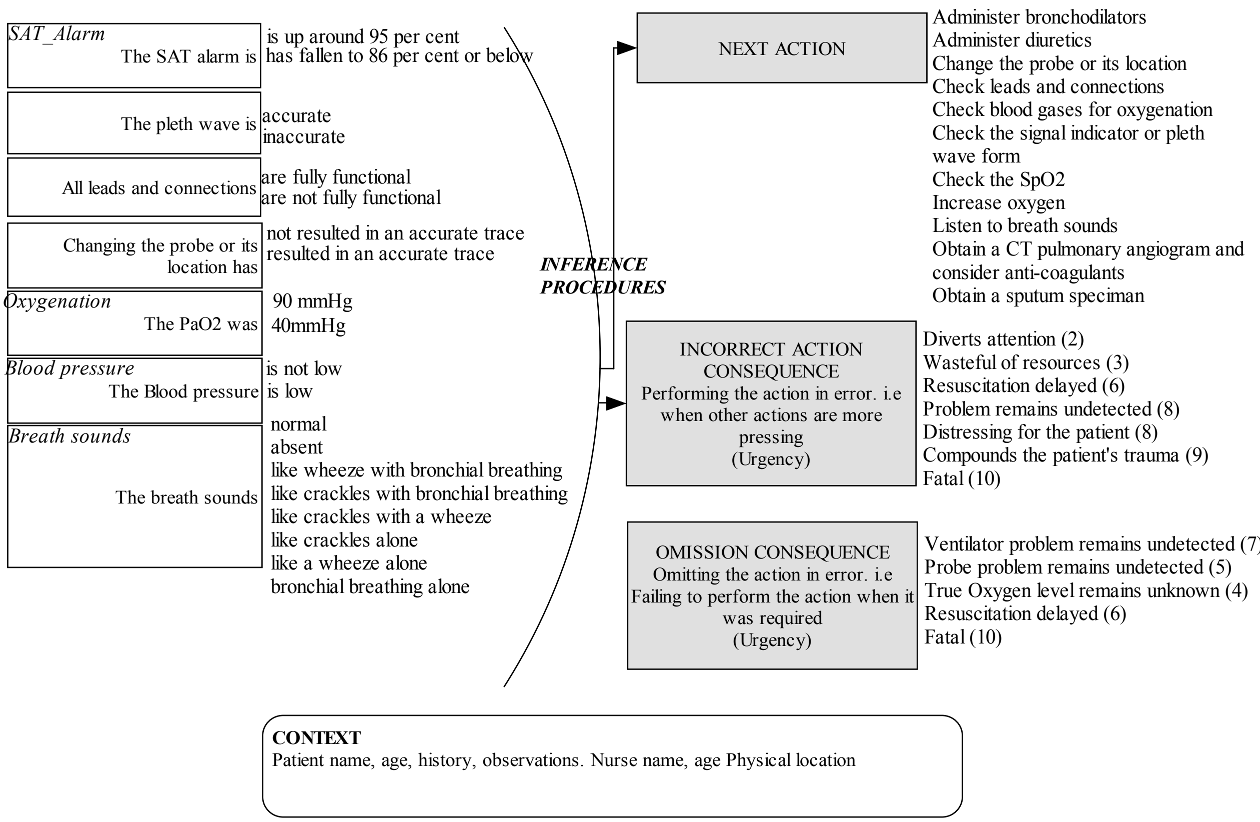

Figure 3: ICU Argument tree

The data items (extreme left) represent possible events or causal factors in ICU situations. There are three claim variables (extreme right): 1) the actions an ICU nurse may take at a point in time in a given situation, 2) the consequence that follows if the action is not correct and, 3) the consequence of failing to perform the correct action for the situation. Arrows represent inference procedures that will be invoked to infer a value on each claim variable for any set of input data items.

After initialisation, the IILE functions using a SET-INFER-NARRATE- cycle illustrated in Figure 4.

A prototype IILE with partial functionality has been implemented and evaluated to date. The prototype permits a restricted set of context variables and does not infer the severity of incorrect actions or omission consequences but more simply, presents canned text about the errors to the learner during the narrative phase. The learner has initial input into the story by setting context variable values such as the name and gender of the patient and nurse. *Figure* 5 illustrates the main screen for the prototype. On the left is a list of all actions available to the nurse. The top pane on the right provides the narration to date. Beneath that the learner is prompted to set data item values for the ‘Check the signal indicator or pleth wave” action that was selected prior to the display of the screen in the SET phase. Once an action is selected and a data item value set, the system invokes the inference procedure in the argument tree to determine what the correct next action should be (INFER). If the next action the learner selects is not correct two segments of text are generated for the NARRATE phase; a segment explaining why the action was incorrect and another explaining the consequences associated with the non-performance of the correct action.

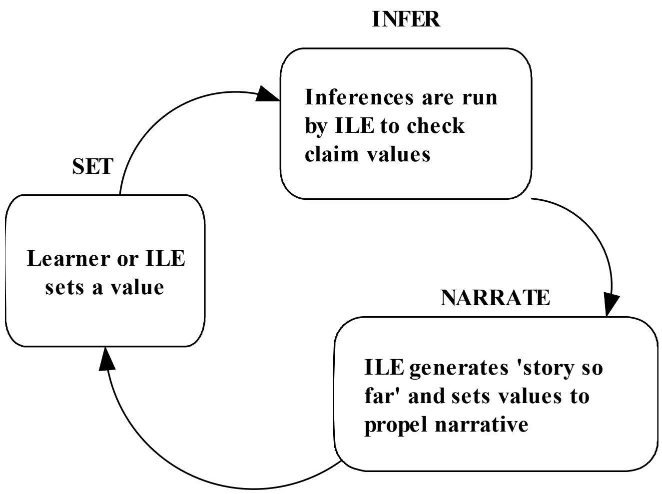

Figure 4: Narrate, Set, Infer cycle

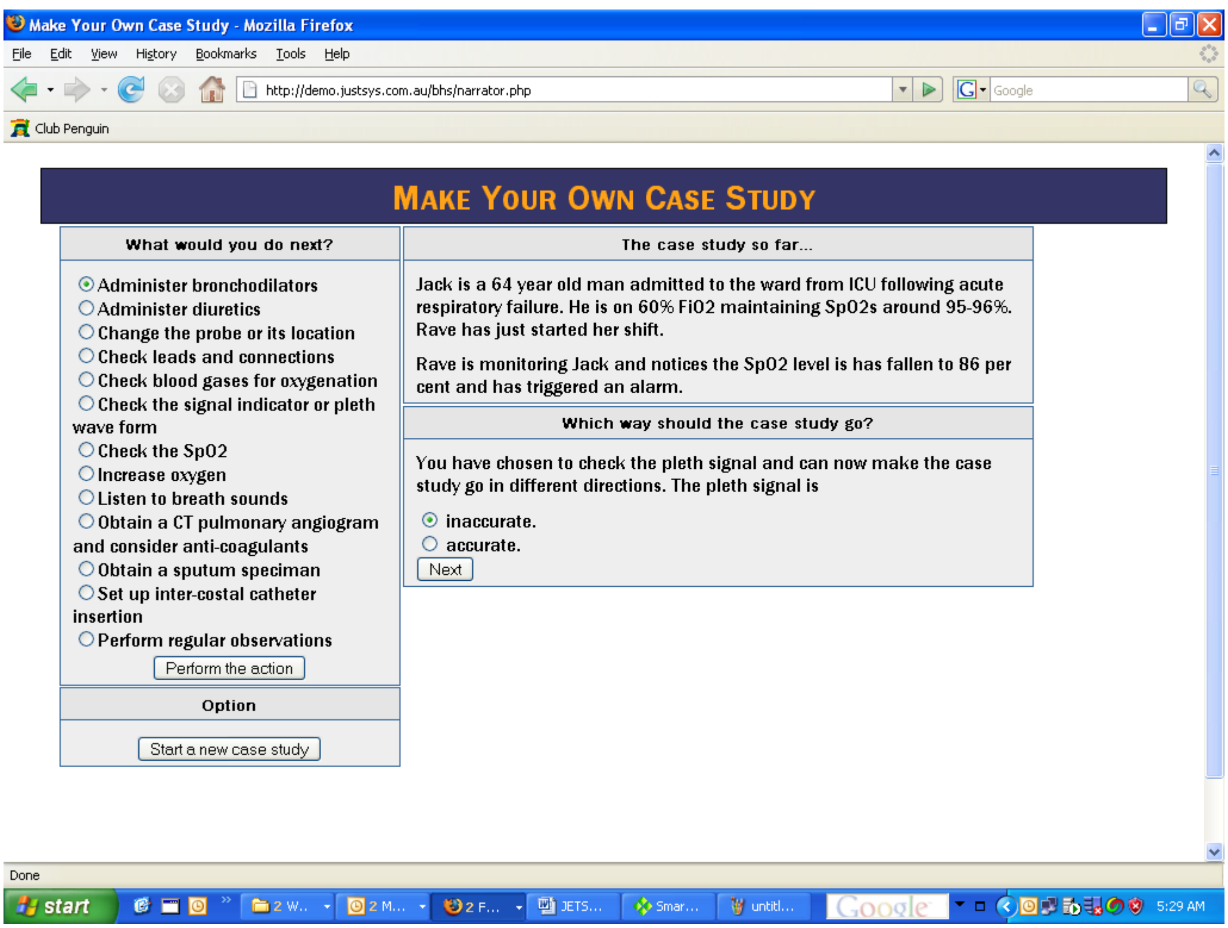

Figure 5. SET phase screen prompting the learner to set Pleth data item values

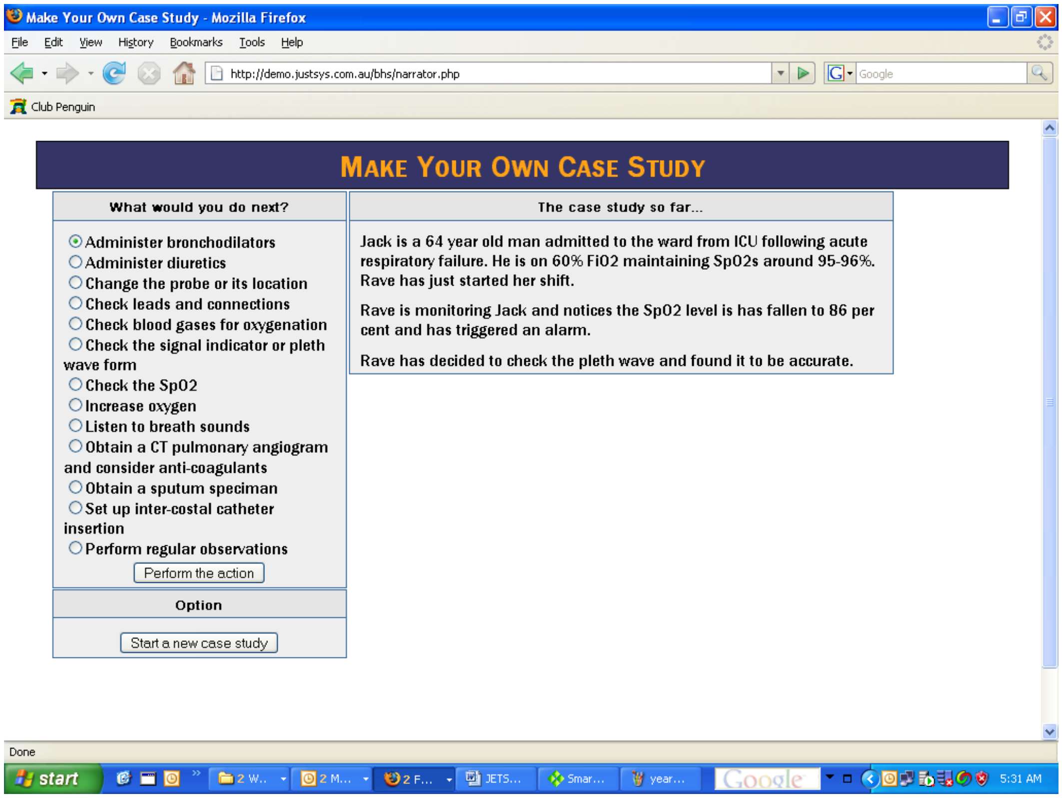

Figure 6. NARRATE phase screen after pleth set to accurate

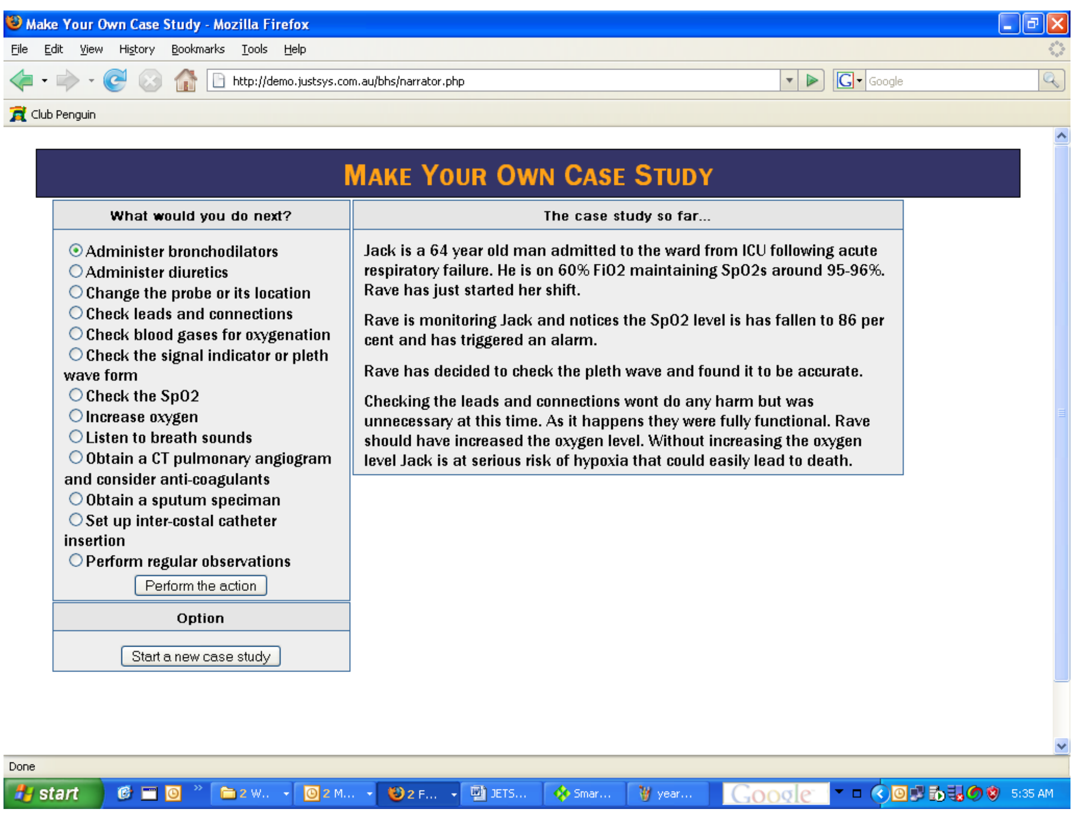

Figure 7. NARRATE phase screen after an incorrect action

Figure 6 illustrates a screen that presents narrators voice back to the learner following the setting of the pleth wave to accurate. The learner is about to select the next action to infer is to check the leads. However, behind the scenes, the INFER phase has determined that the correct action to perform next is to Increase oxygen. **Error! Not a valid bookmark self-reference.**7 depicts the NARRATE phase screen that displays the incorrect action text explaining why checking the leads was not appropriate and the omission text explaining why increasing the oxygen was more important. The NARRATE, SET, INFER cycle continues until a pre-defined end state is reached. These end states depict recovery or escalation of the concern to a point where a doctor is called.

Table 2 illustrates a similar example though differs from the prototype sample above in that the IILE exerts control of events to dramatise the impact of an error and produce a more dramatic story. Initially, at Steps 1 to 7, the learner propels the narrative on sufficiently so the IILE does not intervene but acts only as a narrator providing the learner with an alternate description of the learner's experiences.

At Step 8, the learner erroneously elects to check the breath sounds instead of checking the leads. The noisy pleth wave typically indicates that the finger probe is not accurately picking up a signal so checking the breath sounds is unnecessary. The IILE infers the next action given the situation (i.e "alarm", "noisy pleth wave" and "wheezing breath sounds") is still that leads should be checked. The consequence of not doing this (omission consequence) is that the true oxygen level is not known. The severity of this is rated at 4.

Table 2: Emergent narrative example

PHASE	Step	EVENTS
NAR	1	patient_name(jim), patient_age(jim,60), patient_cxr(jim, bilateral patchy infiltrates), patient_fio2(jim,60%) patient_spo2(jim, 95-96%), nurse(flo).
SET	2	Set(ILE,*SAT_Alarm*,sounding)
INF	3	infer(*Check pleth*)
NAR	4	nurse(observes,*SAT_Alarm*, sounding)
SET	5	Set(learner, *Pleth*, noisy)
INF	6	infer(*Check leads*)
NAR	7	nurse(observes, *Pleth*, noisy)
SET	8	set(learner, *Check breath*, like a wheeze) set(ILE, *Oxygenation*, inadequate)
INF	9	infer(Increase oxygen to 100% and suction)
NAR	10	nurse(observes, *Breath,* wheeze), narrator(tells, *Incorrect action consequence*, Diverts attention), narrator(tells, *Omission consequence*, True oxygen level unknown), narrator(tells, *Oxygenation*, inadequate)
SET	11	Set(learner, *Check ETT function* , functional)
INF	12	infer(Increase oxygen to 100% and suction)
NAR	13	narrator(resolution,*Patient dies*), narrator(tells, *Oxygenation*, inadequate), narrator(tells, *Check breath* instead of *Check lead,*), narrator(tells, *Incorrect omission consequence*, Unknown oxygen level)

In order to make a dramatic impact of the learner's error, the IILE commences to direct the narrative by attempting to set events that would extend the current situation and lead to the maximum omission consequence (i.e death rated at 10) or the maximum incorrect action consequence (i.e. death rated at 10).

The IILE performs a search, essentially by scanning inference procedures backwards, from claim to data-item values, in a goal-driven search. The search aims to find a set of data items that subsumes those currently set (alarm, noisy pleth wave, wheezy breath) and an omission consequence equal to the target (death). The search ends with the addition of the value *is inadequate* set for the data item *Oxygenation* to the currently set items. That is, the forward inference on the set (alarm, noisy pleth wave, wheezy breath and oxygenation inadequate) results in the next action being to increase oxygen to 100% (Step 9) and a consequence that failing to do this would be fatal. The IILE therefore sets the data item *Oxygenation* to - *is inadequate.*

The narration at Step 10 informs the learner of the consequence of performing the last action erroneously. Further, the narrator also informs the learner and that the story has taken a twist in that the patient now has insufficient oxygenation.

..when the SAT alarm begins sounding. Flo checks the pleth wave and notices it is noisy. She immediately checks the breath sounds and hears a wheeze. However, this is not the best thing for her to do because it has diverted her attention from the real problem and she doesn't know the true oxygen level. As it happens Jim has taken a turn and has a very low oxygen level.

At Step 11, the learner again errs by checking the endotracheal tube without increasing the oxygen level to pure oxygen and suctioning. The IILE detects that this is the second error with a fatal consequence and triggers a resolution sequence that will leave the patient dead. Finally, the narrator describes the resolution by informing the learner of the mistakes made and actions that should have occurred.

..As it happens Jim has taken a turn and has a very low oxygen level. Flo checks the endrotracheal tube but has not increased the oxygen intake to 100% O2. Jim has entered seizure due to the low oxygen and has died.

Early on, as soon as Flo noticed a noisy pleth wave she should have checked the leads instead of the breath sounds. Failing to do this meant that she didn't know the true oxygenation which as it happens was critically low. She will do better next time.

In order to make a dramatic impact of the learner's error, the IILE commences to direct the narrative by attempting to set events that would extend the current situation and lead to the maximum omission consequence (i.e. death rated at 10) or the maximum incorrect action consequence (i.e. death rated at 10). This functionality has not been included in the current ILE prototype illustrated in the screens above.

In the next example, a short scenario is generated from a session driven entirely by the IILE. This simulates the presentation of case studies of best practice central to second tier learning illustrated in Figure 1.

Table 3: Automated generation of plausible case example

PHASE	Step	EVENTS
NAR	1	patient_name(jim), patient_age(jim,60), patient_cxr(jim, bilateral patchy infiltrates), patient_fio2(jim,60%) patient_spo2(jim, 95-96%), nurse(flo).
SET	2	Set(ILE,*SAT_Alarm*,sounding)
INF	3	infer(*Check pleth*)
NAR	4	nurse(observes,*SAT_Alarm*, sounding)
SET	5	Set(IILE, *Pleth*, noisy)
INF	6	infer(*Check leads*)
NAR	7	nurse(observes, *Pleth*, noisy)
SET	8	Set(IILE, *Leads*, fully functional)
INF	9	infer(*Change probe*)
NAR	10	nurse(observes, *Leads ,* fully functional)
SET	11	Set(IILE, *Change probe*, not resulted in an accurate trace)
INF	12	infer(*Check oxygenation*)
NAR	13	nurse(observes, *Change probe,* not resulted in an accurate trace)
SET	14	Set(IILE, *Oxygenation*, adequate)
INF	15	infer(Continue to monitor)
NAR	16	nurse(observes, oxygenation, adequate), narrator(resolution,Continue to monitor)

Automated case study generation

In problem based learning and learning through cases considerable resources go into the construction of problems/cases and related resources for supporting learners in enabling users to learn through understanding and solving the problems. The construction of cases depicting past or hypothetical scenarios in a non-interactive format is important for the early stages of the transformation from novice to expert, as illustrated in Figure 1. The automated generation of case narratives from a strong domain model is a useful function of the IILE in a non-interactive mode of control.

In the automatic generation of plausible case studies, the IILE first establishes the setting of the narrative by executing the initialisation phase of the cycle. Following that, the IILE selects actions based on inferences drawn from best practice. The cycles are illustrated in Table 3. The events, depicted as predicate-like clauses in Table 3 are feasibly converted to natural language below with relatively standard natural language generation techniques (from the rich resources stored in the GAAM).

> *Jim is a 60 year old man admitted to the intensive care unit with acute respiratory failure. He has been intubated for the last 3 days. His CXR shows bilateral patchy infiltrates and he is on 60% FiO2 maintaining SpO2s around 95-96%. You are caring for this patient when the SAT alarm begins sounding. You notice that the pleth wave does not appear accurate but is noisy. You check leads and connections and see that they are fully functional. Changing the probes or their position has not resulted in an accurate trace. You take blood gas samples to check saturation and find that these values are adequate.*
>
> *You conclude that oxygenation is adequate despite the probe readings, but proceed to apply the OxyMax procedure. OxyMax is necessary to accurately detect oxygen levels in some patients. You continue to monitor Jim closely.*

Results and Discussion

The basis of the system and its functionality has been illustrated using two examples. The IILE allows the user to interactively interrogate or select actions within a setting and receive feedback in the form of a narrative. The learner is engaged in the respiratory treatment of the patient and tries to act in the way that is best for the patient. To this end they select actions to perform and the IILE responds through the narrator to receive feedback and commentary to improve the user's understanding. The system uses knowledge to recognize incorrect actions or omitted actions by the learner and makes subsequent events occur for dramatic impact on the learner through the narrative. As the narrative emerges from the interaction between the learner and the IILE it provides supportive commentary as the learner reasons correctly but causes increased concern for the learner as reasoning mistakes or omissions are made. The IILE is capable of automatically generating a narrative based on knowledge that has been captured on reasoning to complex practical decisions.

A Web-based version of this design has been built and used as an instructional aid. There are some differences from this design in that the system does not propel the story to a dramatic end but simply narrates what has happened with the narration including advice about the consequences of incorrect actions, omissions as well as consequences of these actions.

The impact of the ILE on learning outcomes amongst student nurses was evaluated in a trial involving three groups of third year nursing students at the University of Ballarat described in Yearwood et al. (2007). Briefly, the study involved the use of three groups of student nurses. One group used the IILE in a tutorial, another used decision tree flowcharts and the third, a control group used a conventional tutorial format. Results from a test common to all groups was used as an objective measure of learning outcomes and subjective ratings of student interactions in the classroom were used as a measure of engagement. T-tests revealed that students who used the flowcharts and those that used the IILE performed significantly better on the common test than the control group. Further, the measures of student engagement clearly favoured the IILE.

Conclusion

We have described the design of a narrative based interactive intelligent learning environment which aims to elucidate practical reasoning about the critical care of acute respiratory patients by generating scenarios that capture the actions of the learner and their reasoning, as a narrative. The approach relies on a strong domain model of reasoning. It is expected that, as knowledge-based systems become more prevalent, models will be more readily accessible though their existence alone will not enhance the transformation from novice to expert. An interactive learning environment that embeds domain knowledge into a narrative scenario in a manner that allows the learner a very large degree of free-will has the potential to aid the transformation. One of the key features of this approach is the mapping from the reasoning represented using the Generic/Actual Argument Model to a narrative model that is illustrated here.

The increasing prevalence of knowledge-based systems will also allow for the rapid development of interactive learning systems that are able to connect naturally to the appeal of narrative in understanding and assimilating knowledge for human users. The approach has been found to be effective for learners over the traditional case-study approach. Further work is proceeding in two directions. An empirical study of the benefit of using this approach in a 3D environment over traditional approaches and refinement of the narratives by incorporating the emotional state of the user in interactive mode.

Acknowledgements

This work was supported by the Australian Research Council.

References

Aleven, A., (2003). Using background knowledge in case-based legal reasoning: a computational model and an intelligent learning environment. *Artificial Intelligence, 150*(1-2), 183-237.

Aleven, V., & Ashley, K. D. (1996). How Different Is Different? Arguing About the Significance of Similarities and Differences. *Lecture Notes in Artificial Intelligence, 1168*, 1-15.

Bennett, W. L., & Feldman, M. S. (1981). *Reconstructing Reality in the Courtroom: Justice and Judgment in American Culture*, Piscataway, NJ: Rutgers University Press, USA.

Black, J., & Wilensky, R. (1979). An evaluation of story grammars. *Cognitive Science, 3*, 213-230.

Bransford, J. D., & Vye, N. J. (1989). Cognitive research and its implications for instruction. In L. B. Resnick and L. E. Klopfer (Eds.), *Toward the thinking curriculum: Current Cognitive Research,* Alexandria, VA: ASCD, 173-205.

Bransford, J. D., Sherwood, R. S., Hesselbring, T.S., Kinzer, C. K., & Williams, S. M. (1990). Anchored Instruction: Why we need it and how technology can help. In D. Nix and R. Spiro (Eds.), *Cognition, education, and multi-media: Exploration ideas in high technology*, Hillsdale, NJ: Lawrence Erlbaum, 115-141.

Bromby, M., & Hall, J. (2002). The development and rapid evaluation of the knowledge model of ADVOKATE: an Advisory System to Assess the Credibility of Eyewitness Testimony. *Paper presented at the 15th Annual International Conference on Legal Knowledge and Information Systems, December 16-17, 2002, London, UK*.

Bruner, J. (1986). *Actual Minds, Possible Worlds*, Cambridge, MA: Harvard University Press.

Chatman, S. (1990). *Story and Discourse: Narrative Structure in Fiction and Film*, Ithaca, NY: Cornell University Press.

Cognition and Technology Group at Vanderbilt (1990). Anchored Instruction and Its Relationship to Situated Cognition. *Educational Researcher, 19*(6), 2-10.

Denning, S. (2001). *The Springboard: How Storytelling Ignites Action in Knowledge-Era Organizations*, Boston: Butterworth Heinemann.

Emmot, K. (1999). *Narrative comprehension: A Discourse Perspective*, Oxford: Oxford University Press.

Frize, M., & Frasson, C. (2000). Decision Support and Intelligent Tutoring Systems in Medical Education. *Clinical and Investigative Medicine, 23*(4), 266-269.

Geoffrey, N. (2005). Research in clinical reasoning: past history and current trends. *Medical Education, 39*(4), 418-427.

Graesser, A. C., & Franklin, S. P. (1990). Quest: A cognitive model of question answering. *Discourse Processes, 13*, 279-303.

Hernandez-Serrano, J., & Jonassen, D. (2003). The effects of case libraries on problem solving. *Journal of Computer Assisted Learning. 19*(1), 103-114.

Herreid, C. F. (1998). What Makes a Good Case? Some Basic Rules of Good Storytelling Help Teachers Generate Student Excitement in the Classroom. *Journal of College Science Teaching, 27*, 163-165.

Hung, D., Tan, S. C, W. S., & Hu, C. (2004). Supporting Problem Solving with Case-Stories Learning Scenario and Video-based Collaborative Learning Technology. *Educational Technology and Society, 7*(2), 120-128.

Iuppa, N., Weltman, G., & Gordon, A. (2004) Bringing Hollywood Storytelling Techniques to Branching Storylines for Training Applications. *Paper presented at the Narrative and Interactive Learning Environments (NILE 2004),* August 10-13, 2004, Edinburgh, UK.

Jarz, E. M., Kainz, G. A., & Walpoth, G. (1997). Multimedia-based case studies in education: Design, development, and evaluation of multimedia based case studies. *Journal of Educational Multimedia and Hypermedia, 6*(1), 23-46.

Kirkwood, W. G. (1983). Storytelling and Self-Confrontation. *Quarterly Journal of Speech, 69*, 58-74.

Mandler, J. M., & Johnson, N. S. (1977). Remembrance of Things Parsed: Story Structure and Recall. *Cognitive Psychology, 9*, 111-151.

Mandler, J. M. (1984). *Stories, scripts and scenes: aspects of schema theory*, Hillsdale NJ: Lawrence Erlbaum.

Merseth, K. (1991). The early history of case-based instruction: Insights for teacher education today. *Journal of Teacher Education, 42*(4), 243-249.

Mayo, P., Donnelly, M. B., Nash, P. P., & Schwartz, R. W. (1993). Student perceptions of tutor effectiveness in problem based surgery clerkship. *Teaching and Learning in Medicine, 5*(4), 227-233.

Mezirow, J. (2000). Learning to think like an adult: core concepts of transformation theory. In Mezirow, J. (Ed.), *Learning as Transformation*, San Francisco: Jossey-Bass, 3-34.

McCloskey, D. N. (1990). Storytelling in economics. In C. Nash (Ed.), *Narrative in Culture: The Uses of Storytelling in the Sciences, Philosophy and Literature*, London: Routledge, 5-22.

Neuhauser, P. C. (1993). *Corporate legends and lore: The power of storytelling as a management tool*, New York: McGraw-Hill.

Peinado, F., Gervás, P., & Moreno-Ger, P. (2005). Interactive Storytelling in Educational Environments. *Paper presented at the 3rd International Conference on Multimedia and ICT in Education*, June 15-18, Cáceres, Spain.

Pennington, N., & Hastie, R. (1981). Juror decision-making models: The generalization gap. *Psychological Bulletin, 89*, 246-287.

Pennington, N., & Hastie, R. (1986). Evidence evaluation in complex decision making. *Journal of Personality and Social Psychology, 51*, 242-258.

Propp, V. (1968). *Morphology of the Folktale*, Austin, TX: University of Texas Press.

Rumelhart, D. E. (1975). Notes on a schema for stories. In Bobrow, D.G. and Collins, A. (Eds.), *Representation and Understanding: Studies in Cognitive Science*, New York: Academic Press, 185-210.

Schank, R. C. (1990). *Tell me a story: A new look at real and artificial memory*, New York, NY: Charles Scribner.

Schank, R. C. (1996). Goal-based scenarios: case-based reasoning meets learning by doing. In Leake, D. (Ed.), *Case-Based Reasoning: Experiences, Lessons & Future Directions*, Menlo Park, CA: AAAI Press, 295-347.

Schank R. C., & Abelson, R. P. (1977). *Scripts, Plans, Goals and Understanding: an Inquiry into Human Knowledge Structures*, Hillsdale, NJ: Lawrence Erlbaum.

Simmons, R. F., & Correira, A. (1979). Rule forms for verse, sentences and story trees. In Findler, N. (Ed.), *Association Networks - Representation and Use of Knowledge by Computers*, New York: Academic Press.

Thorndyke, P. W. (1977). Cognitive structures in comprehension and memory of narrative discourse. *Cognitive Psychology, 9*, 77-110.

Stranieri, A., Zeleznikow, J., Gawler, M., & Lewis, B. (1999). A hybrid rule-neural approach for the automation of legal reasoning in the discretionary domain of family law in Australia. *Artificial Intelligence and Law, 7*(2-3), 153-183.

Stranieri, A., Zeleznikow, J., & Yearwood, J. (2001). Argumentation structures that integrate dialectical and non-dialectical reasoning. *The Knowledge Engineering Review, 16*(4), 331-358.

Stranieri, A., Yearwood, J., Gervasoni, S., Garner, S., Deans, C., & Johnstone, A. (2004). Web-based decision support for structured reasoning in health. *Paper presented at the 12th National Health Informatics Conference (HIC 2004*), July 25-27, 2004, Brisbane, Australia.

Stranieri, A., & Yearwood, J. (2007). *Enhancing Learning Outcomes with an Interactive Knowledge-based Learning Environment providing Narrative Feedback*, Technical Report, University of Ballarat, Australia.

Van Horn, M. (1986). *A guide to expert systems*, New York: Bantam Books.

Vernon, D. T., & Blake, R. L. (1993). Does problem-based learning work? A meta-analysis of evaluative research. *Academic Medicine, 68*(7), 550-563.

Wagenaar, W. A., van Koppen P. J., & Crombag, H. F. M. (1993). *Anchored narratives: the psychology of criminal evidence*, Hempstead: Harvester Wheatsheaf.

Warren, W. H., Nicholas, D. W., & Trabasso, T. (1979). Event Chain and Inferences in Understanding Narratives. In R. O. Freedle (Ed.), *New Directions in Discourse Processing*, Hillsdale, NJ: Lawrence Erlbaum, 5-27.

Wilensky, R. (1982). Points: a theory of the structure of stories in memory. In Lehnert W. G. and Ringle M. H. (Eds.), *Strategies for Natural Language Processing*, Hillsdale, NJ: Lawrence Erlbaum, 459-473.

Yearwood, J., & Stranieri, A. (2006). The Generic Actual Argument Model of Practical Reasoning. *Decision Support Systems, 41*(2), 358-379.

Yearwood, J., & Stranieri, A. (1999). The integration of retrieval, reasoning and drafting for refugee law: a third generation legal knowledge based system. *Paper presented at the 7th International Conference on Artificial Intelligence and Law*, 14-17 June 1999, Oslo, Norway.

Yearwood, J., Stranieri, A., & Avery, J. (2006). Interactive Narrative by Thematic Connection of Dramatic Situations. *Paper presented at the Narrative and Interactive Learning Environments (NILE 2004),* August 10-13, 2004, Edinburgh, UK.