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Keywords. Ill-Defined Domains, Non-Technical Skills, Critical Situations, Virtual Reality Environment.

Abstract. In most domains involving expert knowledge, there is a number of cognitive and social factors influencing how efficient one human being is at correctly assessing and responding to certain situations. These factors, which contribute to the efficient and safe realization of a technical activity, are known as non-technical skills, and correspond to a wide range of cognitive proficiencies such as situation awareness, decision making, stress or fatigue management, but also social skills such as communication, leadership and team working. Different studies have shown the impact such skills can have in the successful resolving of a number of critical situations, even more so in our domains of interest which are medical surgery or driving. In this paper, we take a look at the difficulties raised by the teaching of the technical and non-technical skills mobilized during a critical situation, in the context of TEL within virtual environments. We present the advantages of using a combined enactive and situated learning approach to this problematic, and then take an ill-defined perspective to raise some important designing issues in this respect. We show that some aspects of this problem have not been encompassed yet in the ill-defined domains literature, and should be further studied in any attempt at teaching behaviours inducing technical and non-technical skills in a virtual world.

1 Forewords

This report is the extended version of the paper "An Approach to the TEL teaching of Non-technical skills from the Perspective of an Ill-defined Problem" [1]. The research was supported by the MacCoy Critical project (ANR-14-CE24-0021).

2 Introduction

In most domains involving expert knowledge, there is a number of cognitive and social factors influencing human performance, which are commonly described as Non-

Technical Skills (NTS). In this paper, we aim to showcase the challenges which arrive from the learning of NTS inside a Virtual Environment (VE), and to discuss the potential and limitations of a number of approaches recently used in this domain, in the light of an ill-defined perspective, and under the scope of their application to the domains of driving and medical surgery, two domains where we have access to high quality virtual environments.

What are NTS? They range from purely social skills such as communication, team working and leadership, to cognitive skills such as decision making and situation awareness, and personal resources such as stress and fatigue management. They have been extensively studied in medical surgery [2, 3], and some have been studied also in relation to driving [4, 5, 6]. In these two domains, it has been demonstrated that NTS have an influence, positive or not, on technical skills (TS). Such an influence may be even more important in critical situations, i.e. unique events of variable severity which are hard to anticipate [7]. For example, an unexpected complication during a medical intervention might fall out of the area of expertise of a practitioner, which would require him to firstly, identify his own inability to provide a correct technical response to said situation (situation awareness), and secondly, to decide to ask for help to someone else (decision making). If the patient's health is deteriorating quickly, such a demand might be done under stressful conditions (stress management), which could in turn influence our first practitioner's ability to clearly transmit a diagnostic of the situation (communication). Poor stress management and communication skills from our first practitioner may result in a diagnostic error and a third party committing a technical mistake. Moreover, all of these effects are highlighted in visual-gestural activities which are seen in driving or surgery. Due to their physiological anchoring, they are particularly difficult to formalize.

We discuss in the paper the advantages of using a combined enactive and situated learning approach to this problematic. Virtual Environments (VE) appear appropriate in this perspective. They offer the possibility to immerse the apprentice in situations whose parameters may be controlled from the outside, while mastering the situation's degree of criticality. They also provide facilities with regards to the monitoring of human behaviour thanks to the numerous ways to gather traces of interactions from the learner with the virtual environment, such as actions on simulation controls or perceptions of information emanating from the virtual world. Most VE however, seem to put the main focus on the realism of a simulation, sometimes at the expense of computer assisted teaching capabilities.

Teaching NTS therefore raises a number of research questions related to the construction of an intelligent learning environment, which may be approached under the ill-defined problem perspective, as identified by Lynch et al. [8]. Firstly, while domains of technical activities such as driving or some very procedural aspects of medical surgery are well-defined, there is no formal theory of what is a correct NTS display in response to a critical situation, nor there is a formal theory of how to teach NTS. Secondly, we expect some of the previously mentioned NTS to have high variations among individuals. For example, a situation which is stressful for someone might not be for another, depending on both participants' technical ability as well as the inter-individual differences to stress response between humans. A system evaluating one's ability to cope with stress will have to take into account these variations in order to provide new relevant learning situations. Finally, given that NTS are essentially "behavioural markers that contribute to superior or substandard performance within a work environment" [2], they can be perceived as factors which influence how efficiently TS are executed. We ask that such an influence is reciprocal, and that failure to provide a correct technical response to a critical situation will also influence a participant's non-technical behaviour. The co-dependency between NTS and TS in domains involving technical activity is at the centre of our problem. This falls close to the notion of overlapping subproblems as described by [8], where a task cannot be separated into a continuation of independent sub-problems. However, in the case of NTS evaluation in critical situations, not only are the sub-problems overlapping, the very skills we seek to diagnose overlap as the borders between technical and non-technical expertise can be diffuse.

In this paper, we focus on how to design intelligent learning environment assisted teaching of technical and non-technical skills during critical situations, inside of a virtual environment, and applied to driving and medical surgery. In the next section, we will review more precisely the links between NTS and TS in these two domains according to studies in applied ergonomics and cognitive psychology. Then, we will highlight the benefits related to the teaching of these skills inside a VE, as well as the limitations of such a teaching with regards to current approaches to learning in VE. Finally, we will present approaches which have been used in Intelligent Tutoring Systems (ITS) in order to enable learning in domains presenting similar ill-defined problems. Based on this analysis, we explore some further elements characterizing our domain under the ill-defined perspective and discuss some of the corresponding designing issues.

3 Context

3.1 Non-technical skills in driving and medical environments

NTS can be defined as "the cognitive, social, and personal resource skills that complement technical skills, and contribute to safe and efficient task performance" [9]. They have an influence on the worker's TS and include situation awareness, decision-making, teamwork, leadership, stress and fatigue management, which can either increase or decrease the risks of worker error.

The teaching of NTS has been explored in lengths within the medical domain. Because of the importance these skills have in operating theatres, psychologists have made attempts to evaluate the non-technical proficiency of surgeons, anaesthetists and nurses. These attempts resulted in rating systems such as ANTS [10], or NOTSS [11] where NTS used by medical practitioners were identified from cognitive task analysis, and then decomposed in a series of behavioural markers. With regards to driving, NTS also play an important role and attempts have been made to evaluate some NTS in the handling of a risky situation [12, 13]. NTS evaluation is therefore often achieved from the observation and the rating of behavioural markers by other experts. While this method can result in a fine evaluation of some NTS [2], others, like stress or fatigue management, are difficult to detect this way [10]. However, because they influence technical resources in both domains, their influence should be noticeable in a variation of a participant's TS. Therefore, the means of evaluating a participant's NTS can be found both in their behaviour and also in the variation of their TS.

NTS are often studied under the scope of critical situations. According to Merril [7], these situations are unique, with an inconstant degree of gravity making them hard to anticipate. They also are at the origin of a lot of mistakes, especially in the operating theatre [14]. Critical situations are strongly related to NTS, firstly because a failure to correctly apply a NTS may result in a situation becoming critical [10], and secondly, because when a situation is critical, there is a higher propensity at non-technical failure [15]. We should also note that a situation which may be critical to one person might not be for another, rather, the degree of criticality can vary strongly among individuals. For example, someone who has already been confronted to a situation involving a particular risk will be more likely to understand how this situation should be treated, than someone who encounters it for the first time.

3.2 The use of virtual environments (VE) for learning

Virtual environments for learning have known a growing interest in the last years. Among the features that characterize their design and use, we can cite the possibility to immerse the trainee in a physical environment in which his or her visual-gestural behaviour may be monitored under formalized scenarios [16]. This immersion is key to the involvement of the NTS that we are interested in pursuing. Furthermore, Pearson and McLafferty [17] state that "the use of simulation as an educational strategy of active learning allows the students to develop, refine, and apply their knowledge within a safe environment". This is particularly pertinent in critical situations which may have grave consequences in the case of error, not only in the medical domain [3] but also in driving, where unforeseen events can result in accidents. The evaluation of NTS in medicine has always been done in simulated environments, either in the real world [15] through the use of role play, or through the use of VE [18]. For driving, skills such as Situation Awareness or Decision Making skills were detected through the means of computer based simulations [4] or controlled instrumented cars [19].

Real life simulations are often carefully planned from the start. Therefore, all of the situation's parameters are under control which can simplify process of NTS evaluation (the experts know which elements to consider) however, such a planning requires a lot of preliminary work in order to prepare the scenario, and while the evaluation itself is indeed simplified, this task restrains the possible number of critical situations which can be proposed to the learner. Real-life simulations become one off exercises, with little reusability. This approach therefore has a number of downsides, especially with regards to the learning strategy related to the teaching of NTS: in most cases, training is the result of NTS evaluation and a post-simulation debriefing. Overall, at least in the medical domain, such a training resembles more as a series of attempts at raising awareness at the importance of NTS in critical situations rather than teaching skills which may be gradually improved by the learners. In order to provide a larger number of learning situations, the use of VEs strikes us as appropriate, as the possibility to manipulate every element inside a virtual world can provide higher resources availability [20]. In other words, VEs can potentially generate an important number of critical situations inside of which NTS can be tested, allowing the construction of a true strategy for the learning of NTS.

Because VE's create a safe learning environment and can provide multiple unique critical situations for the learning of NTS, they can strongly contribute to the successful training of these skills. Our objective is to provide an efficient VE for the training in NTS in different domains by targeting the critical situations which are the more adapted to the specificities of each learner, given a number of constraints such as the duration of a training session (about 1 hour) and the limited number of training sessions for a learner. In the next session, we will first present a number of interaction-based approaches to teaching in VE, then explain why the learning of NTS inside a VE needs to take into account the differences among learners, and why it is necessary to model the learner's knowledge in order to maximise the efficiency of the learning experience. What is of interest is the kind of coupling that may be achieved between the learner's skills and behaviour and the scenarios played by the virtual environments. As we will discuss in the following paragraphs, this coupling leads to ill-defined issues that are particularly interesting to consider in the VE context.

4 Modelling the interaction between learner and VE

The existence of the aforementioned links between NTS and critical situations underlie the necessity to place the interaction between learner and VE at the centre of our approach, in order to provide the most relevant situations for the learning of NTS. There are different approaches to learning which put the interaction of an individual with the world at its centre, two of them being the enactive approach to learning and the constructivist-based situated learning. In this section, we will present both of these approaches with their benefits and downsides, and explain why it is necessary to have a modelling of the learner's knowledge in order to teach NTS.

4.1 The enactive approach

A first approach to this representation can be found in the principle of enaction [21]. When transposed to Virtual Reality, an enactive system is a system constructing a world, while being constructed by it [21]. In this view, the coupling between the VE and the user is intrinsic as an individual's actions will result in a modification of the world by the system, and vice versa. Knowledge therefore becomes the result of this interaction between individual and world, and can be found in the perceptions and actions traces that this interaction creates.

Given that the system evaluates learning as the result of the interactions between an individual and the virtual world, in this approach knowledge is purely empirical, and can therefore be evaluated from a phenomenological perspective. The focus is put on what the learner experiences directly, and knowledge can be seen as either structural (i.e. describing the properties of the world), factual (i.e. describing the current state of the world) or case-based (i.e. describing a number of correct decisions when confronted with a situation) [22].

The main benefit of this approach, when it comes to the teaching of NTS, can be seen in this phenomenological perspective to learning. Since knowledge is the result of empirical experience, learning becomes highly specific to an individual. Considering the nature of the skills we aim at teaching, the ability to take into account individual differences for the learning of NTS is crucial and therefore this interaction-centred approach is appropriate in that matter. Moreover, in order to be efficient, the enactive approach has to put the credibility of the virtual world in its centre [23]. Because knowledge is the embodied consequence of the perceptions and the actions of an individual on a world, said world (in our case the enactive VE) has to be able to react and modify itself according to the learner's actions so that learning takes place. Therefore, and because of this focus, enactive VE are deemed as appropriate in our case where the learner is confronted with critical situations that he or she will have to address, and whose consequences will highly differ based on his or her actions.

However, while there are benefits in terms of learner modelling, downsides exist when it comes to the teaching of NTS as a whole. The fact that we target empirical knowledge rather than a specific skill may result in a loss of efficiency when it comes to selecting a new learning situation. For example, an enactive system may evaluate a learner's behaviour in a certain situation with a degree of validity, and propose a new situation based on this evaluation, but it will not try to identify the specific NTS which was deficient. Therefore, the choice of a new learning situation might lack some degree of precision when it comes to targeting the skills that really need to be improved for a learner. Being able to assess which NTS in particular should be improved could greatly increase training effectiveness. This constraint is even stronger in our domain where we plan to teach NTS in driving and medicine in VE's, and therefore are subject to the time constraints of the training sessions. Because a session only lasts one hour, being able to select more accurately the most important skill to target for a given individual is very important. Some modelling of the learner's knowledge to ascertain which skill needs to be focused upon is therefore needed.

4.2 Situated learning and the constructivist approach

Another approach to the modelling of the interaction between a learner and a VE can be found in an extension of the constructivist view to learning initially proposed by Piaget [24]. According to Piaget, learning originates from the interaction between a learner and the world and "should be situated in realistic settings and testing integrated with tasks, not treated as a separate activity" [25]. However, in this view and more precisely in one of its expansions, namely the situated learning approach, the type of knowledge is central to learning [26]. While enaction, constructivism and situated learning share the notion of interaction as being central to the emergence of knowledge, the latter argues that different types of teaching should be applied to different natures of knowledge.

Applied to VE's, situated learning approaches often come with an important background work in order to understand the knowledge underpinnings characterizing a domain. A task is evaluated, not only in the representation of the interactions between VE and learner, but also in the specific knowledges involved in each of the learner's actions or strategies [26]. Knowledge being de facto represented for a learner, targeting specific elements of the domain become possible. For example, in TELEOS [26], an ITS for the learning of orthopaedic surgery built within a situated learning paradigm, the distinction is done between the types of knowledges. The type of the feedback will change whether it is an empirical or a declarative aspect which is targeted.

The benefits of this approach are seen in this understanding of which type of knowledge is actually being mobilized by the learner. Because we have deconstructed the learner's actions in the world as a result of certain skills being used, we can target with more precision the ones which might be deficient. This seems especially appropriate in our problematic of NTS and TS learning in virtual environments. Some NTS and most of the TS in the medical and driving domains can be noticeable through cognitive task analysis. Therefore, they may also be identifiable in a VE through a careful decomposition of these skills in terms of knowledge types. In this respect, the situated learning approach is interesting, because a precise evaluation of these skills can help the system determine which ones need to be improved for a given learner.

Drawbacks come from the lack of a clear pedagogic strategy which translates in a deficit of efficiency when it comes to integrating the training in a learning curve. Because the focus on the type of knowledge is so strong, feedback only takes place outside of the virtual world, and will be less connected to the actual learning environment. In situated learning applied to virtual environments, the interaction between learner and system is important, but may sometimes be overshadowed by knowledge of the domain itself. Given the specificities of NTS and their links to situations which are by essence unique, we argue that they should be best taught by the empirical experience of a large number of critical situations. While knowledge of the domain is key to know which skill should be targeted for a given learner, we hypothesize that the teaching of NTS should be done by a succession of empirical experiences, and not through post simulation feedback.

4.3 Exploring criticality through the construction of knowledge

We saw earlier the interests of adopting an enactive approach for the teaching of NTS in VE. According to this approach, learning is the embodied consequence of an individual's interaction within the world in which he or she evolves. In our case, this means that the NTS will be learned by a succession of confrontations between the learner and critical situations, under the assistance of immersive teaching methods. This is a logical conclusion because NTS are non-procedural by nature, rather, they appear to cope specifically with the lack of an adapted procedure to deal with a given situation

[27]. For all these reasons, our approach should first of all be underpinned in the principles of enaction applied to VE.

However, it should still be necessary to adopt some aspects of situated learning, more precisely, the modelling of knowledge, in order to reach a higher training efficiency. Critical situations are by nature challenging, and some challenges may simply be too hard for a learner given a certain degree of technical and non-technical expertise. On the opposite side, a situation which would be deemed as critical for someone will not be for another person who may have already been confronted to a similar situation. A situation may therefore be critical for an individual and not for another, depending on their TS level and the way they can handle the non-technical aspects related to it. For example, a patient in mortal danger needs to be treated according to a technical procedure known by the surgeon. Such a situation will be more or less critical depending on the nature of the practitioner. A surgeon with an average stress management ability will find it more difficult – i.e. critical – than one with a high score of stress management. Therefore, in order to provide efficient NTS training, it is necessary to target situations which have the right degree of criticality for a specific individual. If the degree is too low, the situation will not be critical and therefore NTS will not be mobilized. But if the degree is too high, the situation will simply be too difficult and a failure can have a very negative impact for the learner. Providing the right degree of criticality is crucial to the good teaching of NTS, therefore, some form of knowledge modelling is in our case, necessary.

We orient ourselves in the direction of an enactive VE including a degree of learner's knowledge modelling. In other words, we aim at evaluating the learner's performance in terms of TS and NTS inside a critical situation, while respecting the principles of enaction in order to maintain the necessary degree of realism for the simulation. The evaluation of a learner's skill level when confronted with a given problem has been explored at lengths in the ITS literature, let us explore the difficulties such a knowledge modelling problems poses in an interaction-centred VE such as ours.

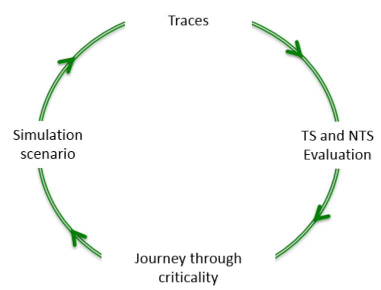

Fig. 1. In order to teach NTS in a virtual world, the system will be fed with a number of data corresponding to a learner's behaviour. Theses traces lead to the evaluation of the learner's TS and NTS level. From this diagnostic, a new learning situation can be selected and then played which will result in new traces being produced and a new evaluation process being done.

5 Teaching non-technical skills inside of a virtual world: issues from an ill-defined perspective

In 2006, Lynch et al. [8] attempted to cover the different aspects which made a teaching problem ill-defined in an ITS Framework. Following this breaking down, researchers argued that knowing which aspects of a problem were ill-defined could provide insights for the choosing of the more appropriate modelling technique [28], and started questioning whether an ill-defined teaching problem should be divided in the two notions of *domain* and *task* [29]. Fournier-Viger et al. [28] suggested that because the main focus of an ITS was to provide the learner support to individual tasks, the notion of domain might be unnecessary. Looking at the problem of NTS teaching inside a virtual world, this distinction appears useful in order to illustrate the specificities of our twofold approach. Situated learning aims at representing the specificities of the knowledge we seek to teach and as such raises research questions which are purely related to the domain, while the enactive approach may represent the interaction-centred challenges related to the learner's realization of a given task. In this session, we take a look at the modelling of NTS inside of a virtual world from the perspective of both the domain and the task, following [8]'s definition of what characterizes an ill-defined problem. We also point out some further aspects that have not been encompassed yet in the ill-defined problems literature.

5.1 The ill-defined problems related to situated learning and knowledge modelling.

When it comes to modelling learner's knowledge, one of the main criteria characterizing ill-defined domains is the absence of a complete formal theory of the domain. Here we actually aim at evaluating two different domains, which are technical and non-technical skills in driving or medical surgery. Taken separately, are these two-domains ill-defined?

Is technical expertise ill-defined? A technical gesture, whether it is in driving or in medical surgery, is partly declarative, partly procedural and partly empirical; in other words, it corresponds to the good choice of a given procedure preferentially to another, and the good implementation of such a procedure. While some aspects related to the evaluation of a TS in a VE may well be ill-defined, the description of a technical gesture in itself is almost always known and clearly defined. For example, in driving, hill start in a manual car can be described as: (1) lift the handbrake, (2) disengage, (3) pull-away slowly while handing down the handbrake. Theoretically, it is a succession of gestures produced in a certain order. Therefore, TS in themselves seem to have a degree of formal theory.

Is there a domain theory of NTS? Cognitive skills such as situation awareness and decision making, and social skills such as team working have been identified through the means of cognitive task analysis, when evaluated in real-life simulations in the medical domain [2, 11]. If such an analysis is possible, then these skills should be well-defined theoretically. Other NTS such as stress management for example, have been defined by psychologists or work specialists. From the early work of Lazarus in 1966 [30], the effect of emotion on behaviour has been studied in depth. A cognitive-motivational-relational theory of emotion has been proposed, emphasizing in particular the mediating processes (cognitive appraisals of situational demands and personal coping efforts) that affect the relationship between a person and its environment.

In themselves, both technical and non-technical skills have a degree of formal theory. The definition varies in function of the technical domain, but it is certainly more defined than the more exploratory aspects of astrophysics for instance, one of the examples proposed by [8] in order to illustrate domains without a formal theory. We argue that our domain, though, is still ill-defined knowledge-wise from a perspective that has not been covered by [8]'s definition, because technical and non-technical skills are involved in a single perceptual-gestural activity. Even if both aspects are partially ill-defined in themselves, the central difficulty can be found in that they appear in the same gestures; therefore, evaluation-wise, technical and non-technical abilities overlap. We face here a case where two different domains overlap and can only be observed together. Taken separately, they are well-defined. Put together, they become ill-defined as the ties between them are diffuse and can change from one individual to another. We ask that this is a new form of problem not yet identified by previous approaches to ill-defined domains, and which should be encountered whenever the goal is the evaluation of a perceptual-gestural activity expressing multiple skills being used. In addition to this, this ill-defined knowledge problem also affects the rating of a situation's utility with respect to the learning of these skills, and the learning task itself must be approached as ill-defined.

5.2 The ill-defined problem of performance evaluation related to enactive learning of non-technical skills

Enaction states that knowledge emerges from the mutual modifications between a learner and a world, therefore, in order to learn, an individual has to be strongly coupled with the world, which in turn needs to react and modify itself in function of the individual's actions. The challenges raised by adopting an enactive approach to NTS learning in VE, illustrated in figure 2, can also be considered as the following ill-defined problems.

- The sub-problems overlap, as any of the learner's actions on the virtual world will result in a change of the situation, which will either increase or decrease the importance of further actions from the learner. For example, in the case of a driving simulation, if the learner has correctly perceived the potential presence of a pedestrian dissimulated by a truck yet about to cross the road, he will be able to gradually slow down, therefore decreasing the degree of importance of another problem, such as the car tailgating him within which the driver might have been surprised by a brutal braking. Both of these aspects need to be considered together and not independently as their characteristics change simultaneously.

– The task structure becomes ill-defined, and more accurately, it becomes analytical with the number of possible correct paths changing as a result of this pseudo-real-time coupling between learner and world. In driving for example, two drivers might adopt a similar strategy in response to a critical situation, but may implement this strategy with different degrees of efficiency. The way they perceive a situation and its degree of criticality is mediated during the course of their perception-action loop; this perception-action loop is in turn mediated by their technical and non-technical skills and by the perception of their own performance. Such a variability needs to be taken into account for the system to interact with the learner's actions, or in other words, to determine which feedback the VE will produce. Rather than a definite task structure, the issue is to model the singular experience of a learner trying to maintain his or her TS in front of a critical situation. Following the coupling envisioned in figure 2, the role of the ITS is then to drive the learner in a personalized "journey through criticality", assessing the coverage of a number of critical situations, and the involvement of a number of NTS.

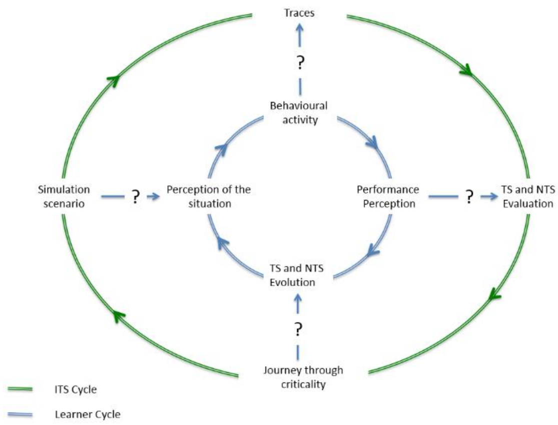

Fig. 2. The coupling between user and system can be found at any stage of the training session. Behaviours (i.e. successions of perceptual-gestural activities) from the learner are processed and result in a series of traces. After a given critical situation is over, the performance perception should be double: the learner evaluates his own performance based on his perception of his behaviour during the situation, while the system uses the traces in order to evaluate TS and NTS. Experiencing a critical situation, the learner's TS and NTS level evolve and in parallel, the system adapts to this evolution by proposing a relevant new critical situation. While unfolding, this new critical situation will be perceived by the learner which will generate more perceptual-gestural activity, i.e. new behaviours.

A further look into these two characteristics of an ill-defined problem, which are specific to our interaction-centred approach, can be found in a more recent breaking down of ill-defined problems proposed by Nguyen-Thinh et al. [31]. The authors choose to look at learning as a succession of problems to solve in order to determine their degree of ill-definedness. Teaching domains become more or less ill-defined depending on the size of the solution spaces to a certain task. This solution space depends on the number of possible solution strategies, quantifying the existing approaches to solve a given problem, and the number of possible implementations for all of these strategies. At the most well-defined end of the continuum, well-defined problems have only one solution strategy which can be implemented only in one precise way. At the opposite side of the spectrum, a problem such as "the design of an investment simulation system" have an undetermined number of solution strategies and implementations [31]. Determining the position of a problem in this continuum can give an insight as to which technique should be best used in order to teach a problem. Because of sub-problems overlapping and the task being analytical, we ask that there must be quantifiable number of appropriate solution strategies in response to a given critical situation, but an indefinite number of ways to apply these strategies. For example, a driver may have braked after a single glance at an incoming danger, while the other may have focused his gaze specifically on it before doing so. They will have applied the same strategy in different ways.

Following [31] ranking of ill-defined problems in a continuum, we see that similar challenges with regards to performance evaluation have already been treated by the use of hybrid approaches including systems and model tracing for the more defined aspects of the problem-solving task, and datamining approaches in order to learn the more uncertain parts [32]. These approaches however focus solely on the evaluation of a learner's performance. In our case, because the domain in itself also has ill-defined specificities, the learner's performance will need to be looked at from the scope of his knowledge state and the situation characteristics, in order to determine the actual influence NTS had in such a performance. This influence may hold with different degrees: intuitively, the effect of situation awareness or stress management on the learner's performance may appear very different. The situation characteristics may also result in varying degrees of criticality impacting the learner's performance, depending on the learner's sensitivities to a situation's characteristics. Such an approach is necessary in order to provide the more relevant feedback and select the more appropriate new learning situation given the specificities of each learner.

6 Conclusion

In this paper, we have shown the challenges raised by the teaching of NTS during critical situations inside of a virtual world and showcased why, given the characteristics of such skills, it is necessary to adopt an interaction-centred approach coupled with a modelling of knowledge, in order to maximise efficiency and to explore as many dimensions of criticality as possible. We have highlighted the reasons why such a combined approach is an ill-defined problem, both from the point of view of the interaction between the learner and the virtual world, and the point of view of knowledge modelling.

We have seen that some aspects of our problems were already partially explored in the ITS literature. For example, TELEOS [33] deconstructed a technical activity (namely the gestures of a surgeon in orthopaedic surgery) as a coupling of different types of knowledge in order to target the best feedback. CANADARMTutor [32] used a hybrid approach including educational data mining techniques in order to learn a number of correct behaviours for the manipulation of a robotic arm, a task performed in a virtual environment showing a large realm of different possibilities. Both of these works shared some characteristics of ill-defined domains similar with ours, yet CANADARMTutor focused exclusively on the perception of a technical performance, while TELEOS aimed at proposing the most appropriate knowledge-type based feedback. The learning of NTS in critical situations inside of a virtual world will need to enfold both the performance analysis aspects of CANADARMTutor and the knowledge modeling assets of TELEOS, while considering a new aspect of an ill-defined problem, which is taking into account the merging barriers between technical and non-technical expertise.

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