Online-Journals.org

iJAC International Journal of Advanced Corporate Learning

iJAC | eISSN: 1867-5565 | Vol. 17 No. 2 (2024) | OPEN ACCESS

https://doi.org/10.3991/ijac.v17i2.42975

TLIC PAPER

Deontic Knowledge Representation and Reasoning in Industrial Accident Prevention Training by Means of Time Travel Prevention Games

Oksana Arnold[1], Ronny Franke[2], Klaus P. Jantke[3](✉), Rainer Knauf[4], Tanja Schramm[4], Hans-Holger Wache[5]

[1]Erfurt University of Applied Sciences, Erfurt, Germany

[2]Fraunhofer Institut für Fabrikbetrieb und -automatisierung IFF, Magdeburg, Germany

[3]ADICOM Software, Weimar, Germany

[4]Ilmenau University of Technology, Ilmenau, Germany

[5]Institution for Statutory Accidents Insurance and Prevention for Raw Materials and Chemical Industry, Prevention Center Berlin, Berlin, Germany

klaus.p.jantke@adicom.software

ABSTRACT

Industrial accident prevention is an issue of societal relevance to avoid loss of human lives, injuries, damage of installations, and financial losses. The authors deploy game-based training in virtual environments where trainees experience challenges of safe operation and disastrous self-induced accidents. Nothing is more affective and, thus, effective than a trainee's own experience. Time travel prevention games are a game category particularly tailored to the needs of human players who look for opportunities to make good for a damage. Time travel prevention games for purposes such as accident prevention in the industries are advantageous due to their conservation of resources including human health and lives. They are affective by allowing for unprecedented learner/player/trainee experiences and they are effective due to the fascination of application-oriented game play including opportunities to influence the fate, the latter being less close to reality, but the more attractive and worth telling. For optimal guidance to human trainees, the digital game system needs to learn about the trainees' strength and weaknesses, about needs and desires. In terms of behavioral sciences, the system observing a human's behavior hypothesizes theories of mind. In training games, modalities of events/actions are decisive. There are modalities of events/actions such as possibility, unavoidability, and the like as well as obligations. Training aims at the emergence of cognitive states that are useful in practice. The system's reasoning is deontic.

KEYWORDS

industrial accidents, accident prevention, prevention training, training experience, time travel prevention games, adaptivity, trainee modeling, theories of mind, modal logic, deontic logic, theory of mind induction

Arnold, O., Franke, R., Jantke, K.P., Knauf, R., Schramm, T., Wache, H.-H. (2024). Deontic Knowledge Representation and Reasoning in Industrial Accident Prevention Training by Means of Time Travel Prevention Games. *International Journal of Advanced Corporate Learning (iJAC)*, 17(2), pp. 4–16. https://doi.org/10.3991/ijac.v17i2.42975

Article submitted 2023-07-10. Revision uploaded 2024-01-05. Final acceptance 2024-01-11.

1 INTRODUCTION

For the purpose of accident prevention training, modalities of events and actions play a key role. The advantage of time travel prevention games lies in the opportunity to impact the fate, to change modalities. This requires preferably deontic reasoning.

1.1 Accident prevention training with time travel prevention games

Time travel prevention games have been introduced on the conference and expo German Prevention Day 2015 [2]. In these early days, the main focus of research and development was on game-based crime prevention [3]. The focus has moved toward industrial accident prevention [4]–[7], a challenging domain of great societal relevance.

In a time travel prevention game, trainees experience difficult and sometimes risky tasks at virtual locations as on display in Figure 1—screenshots from real applications.

Fig. 1. Two VR workplaces by Fraunhofer IFF developed for accident prevention training

According to the complexity of risky industrial processes, a training session may end in an undesired state as visualized by screenshots from training sessions in Figure 2.

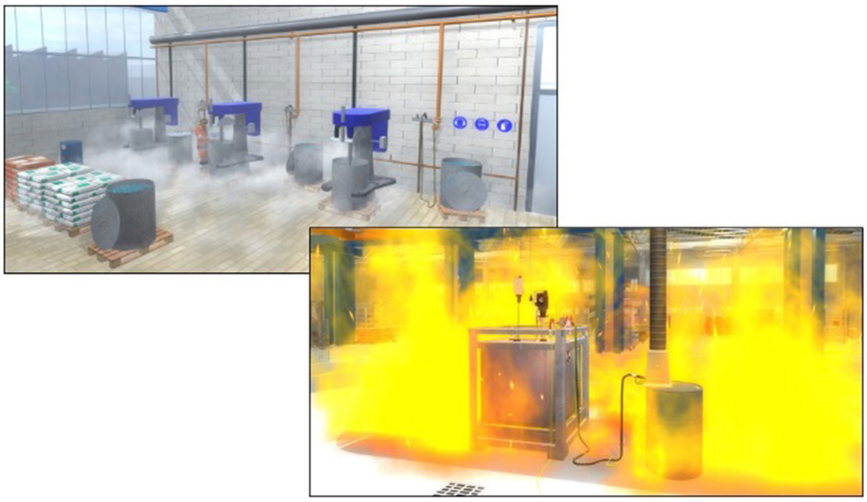

Fig. 2. Two less successful outcomes of inappropriate human trainee actions

The gist of time travel prevention games is to enable trainees to impact the fate, so to speak, by traveling back in time for another trial and to make good for the damage.

1.2 Modalities and deontic thinking in accident prevention training

If human training activities lead to undesired events like those on display in Figure 2, it stands to reason whether this was unavoidable or not.

The two screenshots on the right in Figures 1 and 2, respectively, are taken from a module for training to decant inflammable fluids. The number of potential actions that may cause an accident—as on display in Figure 2—is astonishingly high.

By way of illustration, think of an electricity issue such as grounding. There are two grounding cables available. One is wall-mounted and the other one is two-sided. The wall-mounted grounding cable may be attached to either the source container or the target container. The two-sided cable is to be used for connecting both containers. It is, perhaps, not obvious that the wall-mounted cable should be used prior to the connection of the two containers. The connection of the containers may bring with it a potential equalization. In some cases, this results in an accident.

Using words from Garson [8], "modal logic is, strictly speaking, the study of the deductive behavior of the expressions 'it is necessary that' and 'it is possible that' …" From the unavoidability of an accident—it is necessary that—we are lead, as in the case discussed in the preceding paragraph, to normative expressions like 'should be'.

This modality sounds more like an obligation. That is what deontic logic is about. Artificial Intelligence (AI) invoked to "think" about appropriate guidance of trainees in time travel prevention games shall not only reason about possibility and necessity, but must take into account aspects of human thoughts and actions including obligations, beliefs, errors, misconceptions, and the like. Formally, the AI reasons deontically.

1.3 Virtual time travel and adaptive guidance

For a human when training in a time travel prevention game, the apogee is to travel back in time to impact the fate. Changing the past may change modalities of events. However pleasant, different trainees may experience game-based training differently. Most of them are not used to time travel and, thus, are not always able to draw benefit from such an extraordinary chance. Undesired events such as accidents may occur repeatedly causing the need for another journey back in time.

For effective training, human trainees shall finally succeed and, in particular, shall experience the mastery of the mission as own success. Training that is affective bears the potential of being effective and sustainable.

It is the game AI's duty to guide human trainees in a highly personalized manner to a success that is experienced as the own one. For this educational purpose, there have been developed so-called cascades of concepts of a more and more strict, ultimately successful user/player/trainee guidance [7].

To adapt to the strengths and weaknesses, the needs and desires of a human trainee, the AI needs to learn about the background of the human's behavior. This includes the creation of hypotheses of the human thoughts with emphasis on deontic opinions about permission, interdiction, option, obligation, ought, and the like.

2 FROM MODAL LOGIC TO DEONTIC LOGIC

Modal logics—the plural is justified by the manifold of approaches—are behind the reasoning whenever problems of avoiding undesired events are treated formally. The following diagram borrowed from Garson [8] provides just an overview of the currently most popular variants of modal logics.

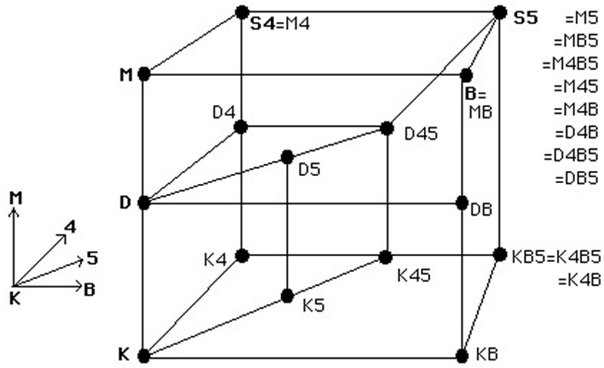

Fig. 3. The most popular modal logics according to Garson [8] up to Lewis's system S5 [12]

The present section is intended to set the focus within the space of modal logics to the particular type of logic appropriate to the issue of reasoning about trainee behavior in time travel prevention games.

2.1 The essentials of modal logic

In Figure 2, next to the fire shown in the right screenshot, the left screenshot taken from a training module for the paint and coatings industry visualizes a high degree of pollution by toxic vapor. The aim is to motivate a trainee's thinking about avoidance. The questions for necessity and possibility are issues of modality as said above [8]. Though being non-classical logics, nowadays modal logics appear quite conventional [8]–[17].

For the classical modalities, it is custom to use the operators $\Box$ and $\Diamond$, respectively, with the relationship in mind that $\Box p$ is equivalent to $\neg\Diamond\neg p$, where symbol p is any propositional variable. Both terms represent propositions that may be true or false.

The first axiom systems of modal logic are due to Lewis [9]. In Appendix II of [12] he presents, among others, his system S2 which is his preferred view at modality. Gödel studied an approach that he detected equivalent to Lewis's system S4 (Figure 3) in which the axiom $\Box p \rightarrow p$ is valid [18]. Gödel used the operator name B instead of $\Box$ having the particular meaning of provability (in German: Beweisbarkeit) in mind.

Training goals are "oughts" [19]. Educators want their trainees to acquire domain-specific normative concepts. Mally developed what he called "fundamental principles of the logic of ought" [10]. This developed into what we nowadays call deontic logic.

2.2 Deontic reasoning for accident prevention

The prevention of industrial accidents may be seen from a moral and/or juristic point of view. Most deontic logic is appropriate to moral-juristic interpretation [20]. But accident prevention training has a focus on cognitive states seen deontically.

In deontic logic writings, most authors abandon the modal logic operators $\Box$ and $\Diamond$. They suggest intended semantics by names such as Gödel's B and prefer operators like O for "ought to", OB for "obligatory that", PE for "permissible that", and so on. Allusive operator names do not help, because no operator cares about its name and all operators ignore names of their co-operators. PE is not seen a wimp compared to OB. Whether or not the logic is appropriate to training within a framework that allows for time travel depends on what is valid and what is not. This is best expressed by axioms instead of allusive operator names. Ruzsa exemplifies unbiased axiomatization [20].

Preconceptions of semantics that are reflected by allusive operator names have the side-effect of paradoxes that fool the human expectations. Readers are invited to have a look for Chisholm's paradox [21] and for related efforts to resolve it [22].

The authors derive their approach in this contribution strictly from the application. A few illustrations from time travel prevention games are intended to illustrate details.

Fig. 4. The wrong pump is installed. It holds $\Box$[acc], but not yet [acc]. $\Box p \rightarrow p$ is not an axiom

Variables are no longer propositional. Instead, they represent actions or events, resp. There are domain-specific constants, i.e., atomic actions or events such as [acc] meaning a particular accident and [poll] representing the pollution of a certain area. Obviously, truth-value interpretations are limited. An action/event may take place, perhaps, to some degree such as [poll]. By way of illustration, Ruzsa [20] introduces an operator T (for "transacted") such that Tp means that p is executed or took place. We relinquish a separate execution operator. The truth of an action is its execution. The truth of an event lies in its occurrence and the truth of an experience lies in the exposure to it. Simply, p represents its execution or occurrence and $\Box p$ means the modality in focus of training. Here, the semantics should not be imposed to the reader, but it might help to think of something like the awareness of something unavoidable.

In the authors' application area, neither $\Box p \rightarrow p$ nor $p \rightarrow \Box p$ are axioms. In particular, if some p is unobservable, that the action/event p happens does not directly imply $\Box p$. In games science, this relates to phenomena such as linearity and monotonicity [23].

There is not yet a complete axiomatization of deontic reasoning for training with time travel prevention games. Based on their practical experience [1], the authors suspect that appropriate axiomatizations may vary from one application to the other. Ref. [1] has introduced and surveyed some of the authors' applications. The present paper is considered a supplemented foundation. Although appearing later than [1], this paper is, so to speak, the first one in the area. It seems appropriate to begin with case studies. As Grätzer put it, "however to generalize, one needs experience" [24].

The system S4 introduced by Lewis [12] relies on rules of truncation as follows.

$$\Box \Box p \rightarrow \Box p \qquad \text{(Box Truncation)}$$

$$\Diamond \Diamond p \rightarrow \Diamond p \qquad \text{(Dia Truncation)}$$

This is sound with an understanding of awareness, of awareness of necessity, and the like. The rules are adopted as axioms. This is advantageous for a pragmatic purpose, because the system's AI is aiming at the guidance of trainees (Ref. [1], section 4.2) and the truncation of operator prefixes allows for simplification of system utterances. Notice that (Box Truncation) may be considered a form of reflection.

In contrast, for the same reasons as above, the authors do not accept any axiom that generates iterations of operators. Consequently, Lewis's two axioms $\Box p \rightarrow \Box \Box p$ and $\Diamond p \rightarrow \Box \Diamond p$ are refused as well as the so-called Brouwer axiom $p \rightarrow \Box \Diamond p$. Although the latter makes sense, there is no need for the AI's ability to cavil at what happened. Loosely speaking, a system's utterance of the Brouwer axiom might sound like this: *Look what happened. It's your fault. You should have known that this is possible*.

For the purpose of automated reasoning, operations such as distribution are useful.

$$\Box (p \rightarrow q) \rightarrow (\Box p \rightarrow \Box q) \qquad \text{(Distribution)}$$

$$\Box (p \wedge q) \rightarrow (\Box p \wedge \Box q) \qquad (\wedge \text{ Resolution})$$

$$(\Box p \vee \Box q) \rightarrow \Box (p \vee q) \qquad (\vee \text{ Introduction})$$

Notice that the inversions of the latter two formulas are not considered axioms, i.e. there is neither a $\wedge$ introduction nor a $\vee$ resolution.

The underlying deontic logic is completed by the representation of knowledge that is application-specific as already exemplified before (see, e.g., the caption of Figure 4). By way of illustration, Ref. [25] deals in much detail and precision with technology representation for purposes of automated reasoning (see especially section 2.3.1 and illustrations therein such as Figure 2.5 on page 65) exceeding in size the present paper.

Another part of the domain-specific knowledge base represents what is usually called the game mechanics particularly including virtual time travel (see Ref. [1], section 2, storyboarding of time travel in Figure 3 and the authors' time tunnel in Figure 4).

There is a dynamic part of the knowledge base that consists of, first, the history of play—the training history—and, second, the trainee model seen as a theory of mind.

Due to space limitations, the authors confine themselves to an exemplification of these issues of knowledge representation with some emphasis on trainee modeling by theories of mind.

3 THEORIES OF MIND—MODELING AND INDUCTION

The first aspects of deontic logic appropriate to training of accident prevention with time travel prevention games have been introduced in the preceding section. Before continuation of deontic logic and reasoning investigations, we need to survey the conceptualization where deontic expressions come into play: *theories of mind*. This section 3 provides a certain introduction in a nutshell and the following section 4 is dedicated to tailoring theory of mind reasoning to our time travel prevention games, in this way extending the usage of deontic formalization and reasoning.

3.1 Theories of mind in behavioral sciences

The theory of mind perspective in behavioral sciences is well-established [26], [27]. It helps to interpret animal behavior. The California scrub jay is a prominent example. Birds of this species are food caching. Assume a California scrub jay—name it A—is caching food and is watched by another bird of its species, name it B. When A's job is done, it is flying away. Shortly after, with very high probability, A returns to unearth its treasures and to hide them elsewhere. The scientific assumption is that A has a theory of mind of B. A imputes the intention to steel the food to B.

About a decade ago, the concepts of theories of mind have been carried over to computer science for the purpose of user modeling. Agent A is a computer program hypothesizing a human agent B's theory of mind [28], [29]. It is essential to explicate that theories of mind are usually only hypothetical by nature [30]. This insight leads to certain inductive learning technologies such as identification by enumeration [31]. This, in turn, motivates the study of spaces of hypotheses for theory of mind learning as undertaken in Ref. [29], an issue beyond the limits of the present contribution. Theory of mind induction for user modeling has been implemented [32], [33] and works well in an educational context for the purpose of learner modeling.

3.2 Deontic theories of mind—modeling and induction

To the authors' very best knowledge, to study deontic theories of mind is a novelty. The point of origin is that training aims at the emergence of insights beyond technical knowledge such as causalities. Trainees shall arrive at insights that may be seen as obligations, oughts to do, and the like [1].

Assume [act1], [act2], and [evt1] are names of two actions and an event, resp., in the domain of interest, logically seen as constants. Target knowledge may be modeled by the formulas [act1] $\rightarrow \Box$ [evt1] and $\neg$[act2], e.g.

In the design process of gamification [7], domain experts, educators, developers, and other specialists negotiate training goals that may be written down deontically like [act1] $\rightarrow \Box$ [evt1], e.g. Actions in the virtual training world are identified that are supposed to reflect certain cognitive states. Such an action's occurrence triggers the insertion of a deontic formula into the hypothesized theory of mind of a trainee—this is induction. The AI system is learning by building hypotheses subsequently.

4 THEORIES OF MIND IN TIME TRAVEL PREVENTION GAMES

The issue of induction mentioned by the end of the preceding section is crucial and, therefore, will be discussed next in some depths within section 4.1. The highlight seen from a viewpoint of game-based training and didactics, in particular, is the usage of theories of mind for adaptive trainee guidance to be discussed in section 4.2 below.

4.1 Player modeling as theory of mind induction

User/trainee/player/learner models in time travel prevention games have the form of theories of mind. They consist of two sets of formulas. The formulas are induced throughout game play by interpreting a trainee's behavior. The data processed for the induction of theories of mind are ground, i.e., they do not contain any variable, but domain constants such as action names and event names—what happens, so to speak.

One might ask why there are two sets of formulas, a conceptualization beyond the limits of prior work in computerized theory of mind induction such as [28]–[30], [32]–[34]. There is a, so to speak, positive set of formulas representing knowledge, opinions, and the like imputed to the trainee. Second, for the representation of what seems to be missing, there is a "negative" set. For brevity, we use the notations ToM^+ and ToM^-.

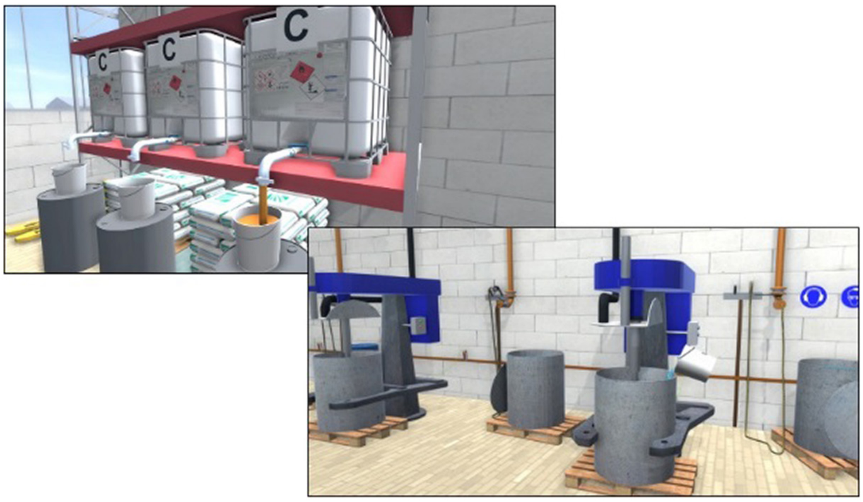

Fig. 5. Filling a bucket with a component of varnish and delivering to a basket mill

When a human trainee deploys buckets instead of jerrycans for the transportation of chemicals, as reported in Figure 5, it is a step of induction to insert $[buck] \rightarrow \Diamond\, [vap]$ into the hypothesis component ToM^-, where [buck] represents the human action and [vap] is an event of vaporization. Note that, in practice, there exists finer terminology.

The axiom $\Box\, p \rightarrow \Diamond\, p$ is adopted what may be considered a Kantian statement. Therefore, the above step of induction should not generate $[buck] \rightarrow \Box\, [vap]$, because this might be an overgeneralization (see [31] for this problem in inductive learning).

When a trainee's behavior changes, e.g., substituting all the buckets by jerrycans, the system may hypothetically move the above formula from ToM^- to ToM^+.

At every point in time—in training or play time, to be precise—the digital system has a hypothetical trainee model that consists of ToM^{+} and ToM^{-}.

4.2 Adaptive player guidance based on theories of mind

A user/learner/trainer/player model, in general, and a theory of mind, in particular, provides a basis to adapt to a human trainee's peculiarities, to needs and desires. Adaptivity is the utterance of the time travel prevention game's artificial intelligence.

Subsequently, a few examples accompanied by the illustrations in Figures 6 and 7 are intended to clarify how to exploit hypothetical knowledge within a theory of mind for the implementation of educationally effective AI behavior. The four screenshots in these figures are from the authors' time travel prevention game module addressing needs of the paint and coatings industry.

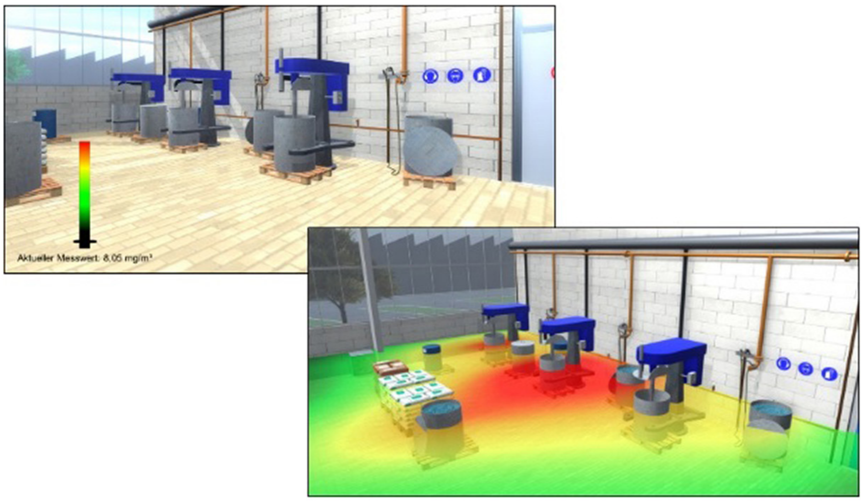

Fig. 6. By reason of varying repeated time travels, suggestive information visualization is aiming at the human understanding and to allow for a trainee's success on her own

The history of play contains the actions executed. These may occur as antecedents in implications like [act1] → ☐ [evt1] and are inevitable when drawing conclusions.

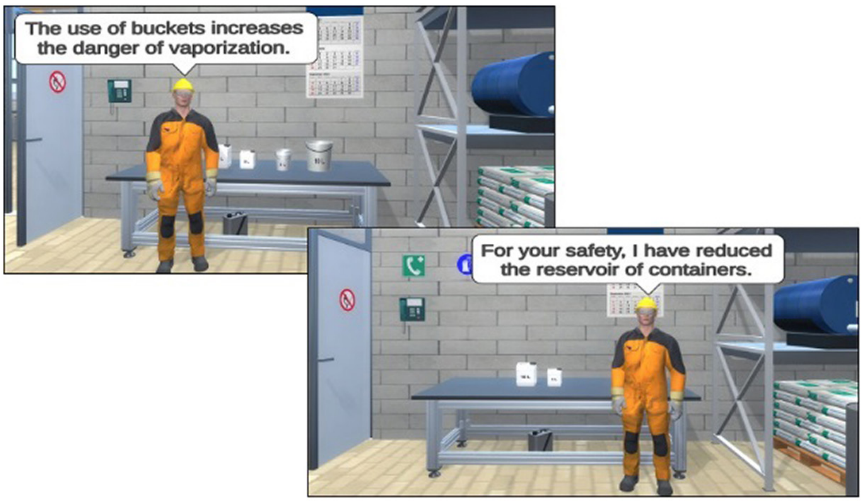

Fig. 7. The past is no longer what it used to be. Formerly unknown avatars can suddenly occur. They talk to the trainee to provide guidance. And game objects may occur or disappear

Assume [evt1] to be the event [poll] meaning a pollution above a certain threshold. In case [act1] takes place, the game AI concludes that it is advisable to inform the trainee about the problem. Figure 6 visualizes two utterances, so to speak, of the game AI addressing the trainee. When the trainee, on a journey back in time, arrives again in the hall of basket mills, a meter occurs (left screenshot) to convey pollution data. The AI's aim is, so to speak, to induce $\Box$ [poll] in the human trainee's cognitive state. If this does not succeed and another time travel becomes necessary, the AI presents a more impressive heatmap (right screenshot).

There have been developed cascades of trainee guidance of an increasing strength aiming at an ultimate success [6], even in case that a trainee repeats erroneous actions frequently and, thus, needs a larger number of journeys back in time.

Much stronger than visualized by means of Figure 6, the past may be changed by the game system. As the authors put it ([5], p. 63), the past is no longer what it used to be.

How to change the past is determined by the current theory of mind. The study of two subsequent cases—for an illustration by means of screenshots see Figure 7 above—is intended to explicate the use of deontic formulas in the theory of mind.

The constant [buck] means the use of buckets for transportation and [vapor] is the event of vaporization. [buck] $\rightarrow \Box$ [vapor] is assumed in ToM^{-}. This expresses the system's hypothesis that the player is unaware of the problems [buck] might cause.

Notice that there exist more intriguing situations. Instead of a single implication, some chain of logical deductions may establish the causal dependence. For brevity, those cases that require a form of logical abduction [35] are ignored here.

If $p \rightarrow \Box q$ is hypothesized to represent missing knowledge, a first quite strong form of adaptivity consists in a colloquial circumscription of the deontic formula under consideration; see left screenshot of Figure 7. For the time being, it is the duty of the game designer team to provide translations like that. Far beyond the current limits, one may imagine a programmed translator from deontic logic to natural language(s).

An even stronger guidance consists in changing the game world such that the action or event p becomes impossible, as illustrated by the right screenshot of Figure 7.

Such a behavior of the game AI that changes the game world substantially may cause questions for the reasons behind. The more drastic the modifications are, the more likely are trainee questions. This brings the present work close to the research and development area of explainable AI, an issue that exceeds the limits of the present contribution. Clearly, it would be attractive to enable a human trainee to chat with characters of the game world about events that took place and actions to undertake.

5 CONCLUSIONS & OUTLOOK

Time travel prevention games are an unprecedented category of educational media. To apply modal logic—deontic logic, in particular—to such an educational area is unprecedented as well. User modeling by theories of mind still is ambitious leading to a formal treatment of conceptual change [36].

In these conditions, surprises are not rare. The authors discovered that by means of the Brouwer axiom one may equip an AI with the trait of being niggling. Perhaps, the use of deontic logic may contribute to more emotional AI in varying forms.

Due to Kripke [37], we have the semantic imagination of different worlds in which modal formulas may be valid. Necessity and possibility in a world refer to the validity of formulas in subsequent worlds. Every time travel in a time travel prevention game becomes a Kripke space journey. Will there be any new discoveries in this universe?

6 ACKNOWLEDGEMENT

The German Federal Ministry of Labor and Social Affairs (BMAS) has supported part of this work and publication. The BMAS—through its Civic Innovation Platform—awarded a prize to the authors' joint project proposal "AI on the Fly" that aims at the low-threshold dissemination to a wide audience of knowledge about human-centered AI concepts, technologies, and applications (German pitch of 3 minutes under the link https://www.youtube.com/watch?v=cfkjdteN3vw).

7 REFERENCES

[1] O. Arnold, R. Franke, K. P. Jantke, R. Knauf, T. Schramm, and H.-H. Wache, "Thinking and chatting deontically – Novel support of communication for learning and training with time travel prevention games," in *Innovations in Learning and Technology for the Workplace and Higher Education: Proceedings of The Learning Ideas Conference 2023*, LNNS, D. Guralnick, M. E. Auer, and A. Poce, Eds., Springer, 2023, vol. 767. https://doi.org/10.1007/978-3-031-41637-8_3

[2] K. P. Jantke, "Time travel prevention games," https://www.praeventionstag.de/nano.cms/vortraege/begriff/Time-Travel-Prevention-Games, 2015. last accessed 2023/07/09.

[3] J. Winter, "Konzeption eines time travel prevention games für die Einbruchsprävention," Master's thesis, Hochschule Furtwangen University, Fakultät Digitale Medien, 2016.

[4] O. Arnold, R. Franke, K. P. Jantke, and H.-H. Wache, "Dynamic plan generation and digital storyboarding for the professional training of accident prevention with time travel games," in *Innovations in Learning and Technology for the Workplace and Higher Education: Proceedings of The Learning Ideas Conference 2021*, LNNS, D. Guralnick, M. E. Auer, and A. Poce, Eds., Springer Nature, 2022, vol. 349. pp. 3–18. https://doi.org/10.1007/978-3-030-90677-1_1

[5] O. Arnold, R. Franke, K. P. Jantke, and H.-H. Wache, "Professional training for industrial accident prevention with time travel games," *International Journal Advanced Corporate Learning*, vol. 15, no. 1, pp. 20–34, 2022. https://doi.org/10.3991/ijac.v15i1.26941

[6] O. Arnold, R. Franke, K. P. Jantke, and H.-H. Wache, "Cascades of concepts of virtual time travel games for the training of industrial accident prevention," in *Innovative Approaches to Technology-Enhanced Learning for the Workplace and Higher Education: Proceedings of The Learning Ideas Conference 2022*, LNNS, D. Guralnick, M. E. Auer, and A. Poce, Eds., Springer Nature, 2023, vol. 581, pp. 53–64. https://doi.org/10.1007/978-3-031-21569-8_5

[7] K. P. Jantke, H.-H. Wache, and R. Franke, "Time travel gamification of learning and training: From theoretical concepts to practical applications," in *Game Theory – From Idea to Practice*, B. Sobota, Ed., Chapter 8. Rijeka, IntechOpen, 2022.

[8] J. Garson, "Modal Logic," in *The Stanford Encyclopedia of Philosophy*, E. N. Zalta, U. Nodelman, Eds., 2021. https://plato.stanford.edu/archives/sum2021/entries/logicmodal/, last accessed 2023/03/12.

[9] C. I. Lewis, "Implication and the algebra of logic," *Mind (New Series)*, vol. 21, pp. 522–531, 1912. https://doi.org/10.1093/mind/XXI.84.522

[10] E. Mally, *Grundgesetze des Sollens: Elemente der Logik des Willens*. Graz: Leuschner und Lubensky, Universitäts-Buchhandlung, 1920.
[11] O. Becker, "Zur Logik der Modalitäten," *Jahrbuch für Philosophie und Phänomenologische Forschung*, vol. 11, pp. 497–548, 1930.
[12] C. I. Lewis and C. R. Langford, *Symbolic Logic*. New York: Century Company, 1932.
[13] G. H. von Wright, *An Essay in Modal Logic*. Amsterdam: North-Holland Pub. Co., 1951.
[14] P. Blackburn, M. de Rijke, and Y. Venema, *Modal Logic, Volume 55 of Cambridge Tracts in Theoretical Computer Science*. Cambridge: Cambridge University Press, 2001. https://doi.org/10.1017/CBO9781107050884
[15] R. Goldblatt, "Mathematical modal logic: A view of its evolution," in *Handbook of the History of Logic*, D. M. Gabbay, J. Woods, Eds., 2006, vol. 7, pp. 1–98. https://doi.org/10.1016/S1874-5857(06)80027-0
[16] J. van Benthem, "Modal logics for open minds," in *CSLI Lecture Notes*, Stanford, CSLI Publications, 2010, vol. 199.
[17] D. M. Gabbay, J. Horty, R. Patent, X. van der Meyden, and L. van der Torre, Eds., *Handbook of Deontic Logic and Normative Systems.* College Publications, 2012.
[18] K. Gödel, "Eine Interpretation des intuitionistischen Aussagenkalküls," *Ergebnisse eines mathematischen Kolloquiums*, vol. 4 (1931/32), pp. 39–40, 1933.
[19] H.-N. Castaneda, "On the semantics of the ought-to-do," *Synthese*, vol. 21, nos. 3–4, pp. 449–468, 1970. https://doi.org/10.1007/BF00484811
[20] I. Ruzsa, "Axiomatischer Aufbau eines Systems der deontischen Logik," *Acta Sci. Math. Szeged*, vol. 26, pp. 253–267, 1965.
[21] R. M. Chisholm, "Contrary-to-duty imperatives and deontic logic," *Analysis,* vol. 24, no. 2, pp. 33–36, 1963. https://doi.org/10.1093/analys/24.2.33
[22] C. Saint Croix and R. H. Thomason, "Chisholm's paradox and conditional oughts," in *Proceedings of DEON 2014, Deontic Logic and Normative Systems*, F. Cariani, D. Grossi, J. Meheus, and X. Parent, Eds., Springer Intl. Publishing, 2014, vol. 8554 of LNAI, pp. 192–207. https://doi.org/10.1007/978-3-319-08615-6_15
[23] K. P. Jantke, "The evolution of story spaces of digital games beyond the limit of linearity and monotonicity," in *Proceedings of the 2nd International Conference on Interactive Digital Storytelling*, Guimaraes, Portugal, December 9–11, 2009. LNCS, I. A. Iurgel, N. Zagalo, and P. Petta, Eds., Springer, 2009, vol. 5915, pp. 308–311. https://doi.org/10.1007/978-3-642-10643-9_36
[24] G. Grätzer, *Universal Algebra.* New York, NY: Springer, 1968.
[25] O. Arnold, "Die Therapiesteuerungskomponente einer wissensbasierten Systemarchitektur für Aufgaben der Prozeßführung," *DISKI*, St. Augustin: infix, vol. 130, 1996.
[26] P. Carruthers and P. K. Smith, *Theories of Theories of Mind.* Cambridge: Cambridge University Press, 1996. https://doi.org/10.1017/CBO9780511597985
[27] J. Call and M. Tomasello, "Does the chimpanzee have a theory of mind? 30 years later," *Trends in Cognitive Sciences,* vol. 12, no. 5, pp. 187–192, 2008. https://doi.org/10.1016/j.tics.2008.02.010
[28] K. P. Jantke, "User modeling with theories of mind: An introductory game case study," Report KiMeRe-2012-05, Erfurt, Fraunhofer IDMT, Children's Media Dept, 2012.
[29] K. P. Jantke, "Theory of mind induction in user modeling: An introductory game case study," Report KiMeRe-2012-06, Erfurt, Fraunhofer IDMT, Children's Media Dept, 2012.
[30] O. Arnold and K. P. Jantke, "Mining HCI data for theory of mind induction," in *Handbook Data Mining*, C. Thomas, Ed., Rijeka, IntechOpen, 2018, pp. 47–68. https://doi.org/10.5772/intechopen.74400
[31] S. Jain, D. Osherson, J. S. Royer, and A. Sharma, *Systems that Learn*. Cambridge, London: MIT Press, 1999. https://doi.org/10.7551/mitpress/6610.001.0001

[32] B. Schmidt, "Theory of mind player modeling: Konzeptentwicklung, Implementierung und Erprobung mit logischer Programmierung," Bachelor's Thesis, Erfurt University of Applied Sciences, Applied Computer Science (Angewandte Informatik), 2014.
[33] B. Schmidt, "Theory of mind modeling and induction: Eine praktische Anwendung," Master's thesis, Erfurt University of Applied Sciences, Applied Computer Science (Angewandte Informatik), 2017.
[34] K. P. Jantke, B. Schmidt, and R. Schnappauf, "Next generation learner modeling by theory of mind model induction," in *Proc. 8th Intl. Conf. Computer Supported Education*, CSEDU, Rome, Italy, April 21–23, 2016, Setubal, SciTePress, 2016, vol. 1, pp. 499–506. https://doi.org/10.5220/0005903804990506
[35] L. Magnani, *Abduction, Reason and Science: Processes of Discovery and Explanation*. New York, NY: Springer, 2001. https://doi.org/10.1007/978-1-4419-8562-0
[36] S. Vosniadou, *International Handbook of Research on Conceptual Change*, 2nd Ed., New York, NY: Routledge, 2013. https://doi.org/10.4324/9780203154472
[37] S. A. Kripke, *Naming and Necessity*. Cambridge, MA: Harvard University Press, 1980.

8 AUTHORS

Oksana Arnold, Erfurt, Germany, Erfurt University of Applied Sciences.

Ronny Franke, Magdeburg, Germany, Fraunhofer Institute for Factory Operation and Optimization IFF.

Klaus P. Jantke, Weimar, Germany, ADICOM Software (E-mail: klaus.p.jantke@adicom.software; ORCID: https://orcid.org/0000-0003-4327-7192).

Rainer Knauf, Ilmenau, Germany, Ilmenau University of Technology.

Tanja Schramm, Ilmenau, Germany, Ilmenau University of Technology.

Hans-Holger Wache, Berlin, Germany, Institution for Statutory Accidents Insurance and Prevention for Raw Materials and Chemical Industry, Prevention Center Berlin.