Cognitive Systems Research 79 (2023) 85–108

Contents lists available at ScienceDirect

Cognitive Systems Research

journal homepage: www.elsevier.com/locate/cogsys

Adaptive dynamical systems modelling of transformational organizational change with focus on organizational culture and organizational learning

Lars Rass [a], Jan Treur [b,*], Wioleta Kucharska [c], Anna Wiewiora [d]

[a] Vrije Universiteit Amsterdam, School of Business and Economics, Nederlands
[b] Vrije Universiteit Amsterdam, Social AI Group, Nederlands
[c] Gdańsk University of Technology, Faculty of Management and Economics, Poland
[d] Queensland University of Technology, QUT Business School, Brisbane, Australia

ARTICLE INFO

Keywords:
Transformational Change
Organizational Culture
Organizational Learning
Safety Culture

ABSTRACT

Transformative Organizational Change becomes more and more significant both practically and academically, especially in the context of organizational culture and learning. However computational modeling and a formalization of organizational change and learning processes are still largely unexplored. This paper aims to provide an adaptive network model of transformative organizational change and translate a selection of organizational learning and change processes into computationally modelled processes. Additionally, it sets out to connect the dynamic systems view of organizations to self-modelling network models. The creation of the model and the implemented mechanisms of organizational processes are based on extrapolations of an extensive literature study and grounded in related work in this field, and then applied to a specified hospital-related case scenario in the context of safety culture. The model was evaluated by running several simulations and variations thereof. The results of these were investigated by qualitative analysis and comparison to expected emergent behaviour based on related available academic literature. The simulations performed confirmed the occurrence of an organizational transformational change towards a constant learning culture by offering repeated and effective learning and changes to organizational processes. Observations about various interplays and effects of the mechanism have been made, and they exposed that acceptance of mistakes as a part of learning culture facilitates transformational change and may foster sustainable change in the long run. Further, the model confirmed that the self-modelling network model approach applies to a dynamic systems view of organizations and a systems perspective of organizational change. The created model offers the basis for the further creation of self-modelling network models within the field of transformative organizational change and the translated mechanisms of this model can further be extracted and reused in a forthcoming academic exploration of this field.

1. Introduction

Organizational culture plays an important role in organizations' success and failures (Johnson, Nguyen, Groth, Wang, & Ng, 2016), as organizational culture offers employees a framework they can apply to reality, which helps them to evaluate what is of significance for the organization and themselves, and what is irrelevant to the organization (Łukasik, 2018). Therefore to be successful in a change of strategy, e.g., towards more sustainability, a change in organizational culture is often inevitable (Bedford & Kucharska, 2021).

Organizational culture is especially important nowadays as is its constant improvement in the context of Health Care, as Covid 19 is putting further pressure on public healthcare systems (Ojogiwa & Qwabe, 2021). Especially constant learning culture in healthcare organizations is vital as it supports their innovation performance thanks to human capital development (Kucharska, 2022). Furthermore, communication and cooperation patterns between employees directly impact care for patients, so demanding circumstances lead to lower-quality patient outcomes (Johnson et al., 2016). Patient safety is naturally the healthcare system's priority, hence many healthcare organisations have deeply embedded safety-oriented cultures. To prevent healthcare safety-related harms, the Institute of Medicine (IOM) recommends a culture of safety, understood as a constant improvement of patient care (Kohn et al., 2000).

* Corresponding author.
E-mail addresses: l.f.science@b-rass.de (L. Rass), j.treur@vu.nl (J. Treur), wioleta.kucharska@pg.edu.pl (W. Kucharska), a.wiewiora@qut.edu.au (A. Wiewiora).

https://doi.org/10.1016/j.cogsys.2023.01.004
Received 18 November 2022; Received in revised form 3 January 2023; Accepted 5 January 2023
Available online 8 January 2023

In this context, the concept of healthcare safety is closely related to constant learning culture composed of such components as learning climate and mistakes acceptance as a natural part of a constant learning process (Kucharska & Bedford, 2020; Kucharska, 2022). Especially in the context of hospitals or patient care, it is understandable that admitting mistakes regarding one's work is difficult, both from an emotional as well as a legal standpoint. However, as studies have shown, the establishment of an organizational culture in which reporting of mistakes and errors is encouraged and instead of punishment or shame the focus is shifted towards a learning process, not only leads to improved patient care but also improves the overall work environment and safety of healthcare workers (Clark, 2002).

To better study the mechanisms of how we can facilitate and encourage such cultural change, considering organizations as complex adaptive systems in which organizational processes are dependent on the interactions of independent individuals (Hazy & Silberstang, 2009) offer an interesting starting point for academic work. Precisely, they exposed that organizational change happens when specific micro-enactments are composed to reframe an organization's capabilities and competencies. In the space between the research concerning organizational culture transitions on the one hand and formalized modelling and network sciences, on the other hand; there exists a void in research about computational modelling of organizational cultural change processes. Although much research has been done on the topic of organizational culture change (e.g., Abdul Rashid, Sambasivan, & Rahman, 2004; Maes & Van Hootegem, 2019; Smit, 2021) and the mechanisms and conditions facilitating it (e.g., Arzahan, Ismail, & Yasin; Chae et al., 2021; Guinea et al., 2019; Walshe et al., 2022), little academic attention has been given to a formalization of these mechanisms and conditions into a multilevel computational model. So, this study focuses on it.

While some formalization exists concerning organizational change in general, e.g. the work by Hazy and Silberstang (2009), or work by (Canbaloğlu, Treur, & Roelofsma, 2021, 2023a) regarding organizational learning, especially in the field of cultural change within an organization is largely unexplored; see also (Canbaloğlu et al., 2023), Chapters 6 and 7. Further current simulations regarding cultural change have mainly focused on cultural change happening in response to a crisis, when employees perform crisis tasks (Beech, Dowty, & Wallace, 2012), rather than examining conditions and mechanisms facilitating persistent cultural change within an organization.

The field of "safety culture" within the context of the healthcare domain has gained rising attention (Halligan & Zecevic, 2011) substantiating academic interest in further exploration and experimentation. Additionally, in the broader context, management scholars have a keen interest in searching and uncovering conditions enabling lasting adoption of sustainability-related practices (Haack, Martignoni, & Schoeneborn, 2021), including safety culture as both an aim to preserve resources and enable sustainable delivery of services. Nevertheless, while some computational models in relation to safety culture in other domains exist (Sharpanskykh & Stroeve, 2011), formal modelling and simulation studies in the domain of health care are still quite underpresented in academic research.

In contrast, research regarding complex adaptive temporal-causal networks, which are the basis of many simulation studies, has been extensive and is documented to be transferable to a large number of different domains (Treur, 2016, 2020). Therefore, an interesting research opportunity arises in connecting the fields of transformational change in the context of organizational culture and learning with computational modelling to create a (Multilevel) Computational Model of Transformative Organizational Cultural Change.

2. Methodology

This paper aims to close the void in research and inter-disciplinary computational scientific work that exists within the field of transformative organizational cultural change (in the context of organizational learning) by creating computational mechanisms and algorithms based on real-world processes.

More specifically the goal of this paper is, to collect information on cultural change and organizational learning processes within organizations, analyse the underlying mechanisms and translate them into computational models. Both to create a formalization of the process in form of a computational model, as well as using simulations, based on this model, to examine and signify the influence of different factors on cultural change and organizational learning.

2.1. *Research logic and philosophy*

As the precise academic situation of the topic of this paper is still under-researched (Sandberg & Alvesson, 2011) within the bigger context of organizational transitions and cultural change, this paper's research logic will be based on an inductive approach, following a "bottom-up" strategy.

As described in Cresswell (2007) this translates into collecting and organizing information from different sources, building themes and abstractions of the found concepts and organizing these towards a general conclusion. To be more precise a "Grounded Theory" research approach is used, as the aim of this paper is to create a new "theory", or in the context of computational modelling a new "model", aiming to explain and exemplify the underlying mechanisms and conditions that enable sustained and transformative cultural change.

As this research aims to explore an underrepresented academic field and examines real-world processes as its basis for theory building, it naturally falls into an ontological research philosophy. More precisely it follows an interpretive/constructivist philosophy combining various sources and perspectives, to better understand the phenomenon of sustained cultural change.

2.2. *Research basis (information collection and analysis)*

As this research aims to build a new computational model of transformative cultural change processes within organizations, and the methodological fit of research is significantly influenced by prior related work (Edmondson & McManus, 2007), the collection of information will follow the academic standard within the field. Examples can be found in (Canbaloğlu et al., 2021, 2023a, 2023b) and (Treur, 2020).

The information collection will be mostly based on a narrative literature review (Tranfield, Denyer, & Smart, 2003) collecting the current state of theory and knowledge within the field of transformational change, cultural change and adjacent concepts. The concepts to be included in the theoretical background of the model will be addressed by their most important and relevant prior studies, and (causal) links between concepts will be enriched and justified by relevant publications. The analysis will be a conceptualization of found common themes, mechanisms and interplays and a subsequent translation of these into a computational causal network model based on connections and behaviour derived from the available literature. The model will be conceptualized around a case study situated within a medical institution in the context of safety and learning culture.

Data is then generated from the (numerical) simulations created by the usage of the model. The data found in this phase will be used for additional analysis, based on a qualitative analysis of the results of the simulation, based on a comparison with previously found data or information (background literature) and other empirical findings in the context of the research.

2.3. *The self-modelling network modelling approach*

The adaptive computational causal network model that this paper aims to create will be based on the computational modelling approach described by Treur (2020) and contextualized in Treur (2021a). This approach focuses on adaptive self-modelling network models, which are characterized by

- the connections between nodes X and Y of the network also called states with activation values $X(t)$ and $Y(t)$ over time
- the weights $\boldsymbol{\omega}_{X,Y}$ of these connections
- the aggregation functions $\mathbf{c}_Y$ of the nodes Y
- the timing of the nodes in the model by speed factors $\boldsymbol{\eta}_Y$

In more detail, it works as follows:

State & connectivity characteristics
The basis of the model consists of interconnected nodes representing real-world concepts translated into a computational context which's connections to other states represent causal relations between the real-world concepts. The connections between the states are further defined by their weights $\boldsymbol{\omega}_{X,Y}$ which determine the strength of influence the value of one note has on another. As we are creating an adaptive network, some connections' weight will be determined by another (self-model) node as explained below.
Aggregation characteristics
Each node or state within a network model can have multiple incoming connections providing input which needs to be aggregated to determine the numerical value of the destination node's state. The effect on the destination node is determined by the chosen combination function $\mathbf{c}_Y(..)$ which will calculate the aggregated impact on the node based on the single impacts $\boldsymbol{\omega}_{X,Y}X(t)$ for the state activation values $X(t)$ and the weights $\boldsymbol{\omega}_{X,Y}$ of the connections.
Timing characteristics
Each state Y's timing or rate of change is further determined by its speed factor $\boldsymbol{\eta}_Y$ which determines how fast it reacts to incoming influences. In adaptive network models, this speed factor can be controlled by another (self-modelling) state as well as being static.

These characteristics are used to formalise and define the internal processes of the computational network model. Emergent from this formalisation an introduction of adaptive characteristics to the computational model is possible by making use of the concept of first- or higher-order self-models.

Self-models
Adaptive characteristics of the networks are introduced by using self-model states added as nodes to the network, representing not a real-world concept or relation, but an internal representation of adaptive circumstances to the model's processes. As two specific cases, the speed factors and the weights adaptiveness of a connection can be represented by such self-model (also called reification) states. The naming convention for the adaptive speed factor representation state is $\mathbf{H}_Y$ and for the adaptive connection weight representation state $\mathbf{W}_{X,Y}$. Similarly, it is possible to also change the characteristics of the chosen combination functions by self-modelling states.

The following related differential (or difference) equations consolidate the characteristics of the network $\boldsymbol{\omega}_{X,\ Y}$, $\mathbf{c}_Y(..)$, $\boldsymbol{\eta}_Y$ into an effect in a standard numerical format:

$$Y(t+\Delta t) = Y(t) + \boldsymbol{\eta}_Y[\mathbf{c}_Y(\boldsymbol{\omega}_{X_1,Y}X_1(t), \cdots, \boldsymbol{\omega}_{X_k,Y}X_k(t)) - Y(t)]\Delta t \tag{1}$$

Here the Y represents the state, X_i the states with incoming connections for Y, $\boldsymbol{\omega}_{X,Y}$ the weight or degree of effect of the specific connection, $\boldsymbol{\eta}_Y$ the rate of change to the destination state and $\mathbf{c}_Y(..)$ the aggregation function used. The computational formalization of a selection of most of the more than 65 often applied mathematical functions can be found in Chapter 9 of (Treur, 2020) in the form of a provided combination function library.

Each of the described functions have different use cases and need to be carefully chosen for each new computational model, based on the best fit for the formalization and modelling of the underlying real-world context. These functions enable a declarative design of network models on basis of mathematical definitions and calculations. An introduction to the different combination functions used in the created model of the current paper is given:

The *identity combination function* **id(..)** transfers the source node's values directly to the receiving node and can only be used on states with only 1 incoming connection. It is further sometimes used to maintain a node's numerical value by a connection to itself, to represent a persistent activation of the node with no decay of its numerical value. The formal definition is as follows:

$$\mathbf{id}(V) = V \tag{2}$$

The *advanced logistic sum combination function* $\mathbf{alogistic}_{\boldsymbol{\sigma},\boldsymbol{\tau}}(V_1, \ldots, V_k)$ combines multiple incoming effects on the node by applying a logistic sum function. It is characterised by the excitability threshold parameter $\boldsymbol{\tau}$ and the steepness parameter $\boldsymbol{\sigma}$. The formal definition is as follows:

$$\mathbf{alogistic}\sigma,\tau(V1,\ \cdots,\ Vk) = [\frac{1}{1+\mathrm{e}^{-\sigma(V_1+\cdots+V_k-\tau)}} - \frac{1}{1+\mathrm{e}^{\sigma\tau}}](1+\mathrm{e}-\sigma\tau) \tag{3}$$

The *steponce combination function* $\mathbf{steponce}_{\boldsymbol{\alpha},\boldsymbol{\beta}}(\ldots)$ is used to model changing context factors that are considered for the model and its environment. It is defined by two parameters $\boldsymbol{\alpha}$ determining the start time of activation and $\boldsymbol{\beta}$ determining the end time of activation. The mathematical definition is as follows:

$$1 \quad \text{if time } t \text{ is between } \boldsymbol{\alpha} \text{ and } \boldsymbol{\beta},\ \text{else } 0 \tag{4}$$

Per the academic standards of the field, the created adaptive network model will be specified in role matrices, a standardized table format further explained in detail in Treur (2020); see also the Appendix Section 8 of this paper. Theoretical research (Treur, 2021b) has shown by mathematical analysis that any adaptive dynamical system can be modelled as a self-modelling network. Therefore, it is expected that this modelling approach will turn out to be a suitable choice in practice as well.

The simulation will then be performed based on the above-given specifications, by use of a dedicated software environment in the form of a provided MatLab script, to be found in Chapter 9 of Treur (2020). Running the script will result in the values of each state over time being calculated based on the dynamics between the states leading to emergent behaviours that will constitute the simulation and its results. The generated data from this simulation will then be exported, visualized and further investigated.

3. Theory - background literature

3.1. General concepts

3.1.1. A systems model of organizational change

While organizational change can be facilitated through different means and can be examined with the help of various theories, the position of this paper suggests a focus on a holistic and system-based theory. This can be found in the systems model of organizational change proposed by Maes and Van Hootegem (2019) which proposes to view organizational change not as a linear process but as a multidimensional mechanism.

In the proposed model organizational change is dependent on 4 key elements of organizational context (namely strategy, structure, people and culture) which are influenced by individual and team effects propagated during change, as well as on the interdependencies between the organization and its external environment which are influenced by organizational effects originating from change within the organization (Maes & Van Hootegem, 2019). In this understanding organizational change can be viewed as an emergent sub-system or behaviour within the systems model of an organization in contrast to being an external process applied.

However, as already suggested by the model and confirmed by further research it is of significant importance that all business units of an organization should be involved in a (cultural) change effort (Ojogiwa & Qwabe, 2021) and that change needs to be facilitated by the participation of all levels operational levels, but especially by leaders, e.g. executives and managers (Łukasik, 2018; Ojogiwa & Qwabe, 2021). High-Level Leadership support is a key necessity and driving force for sustained (cultural) change (Johnson et al., 2016; Wijethilake et al., 2021; Willis et al., 2016) as culture is best established and conveyed by leaders (Schein, 2010). Further, it is of importance that existing assumptions within an organizational system are critically questioned and replaced through a learning process by all of its participants (individuals, teams and organizations) (Mascarenhas, 2019).

3.1.2. Organizational culture

Organizational Culture is one of the most integral parts of an organization (Ojogiwa & Qwabe, 2021). It not only significantly shapes the decision-making processes and behaviours of its members (Farla et al., 2012; Johnson et al., 2016; Ojogiwa & Qwabe, 2021; Markard et al., 2012), but can also, in the case of a strong and good organizational culture, positively influence efficiency, performance, productivity and morale (Łukasik, 2018; Ojogiwa & Qwabe, 2021).

The culture of an organization is thereby mainly shaped by its members' shared values, norms and assumptions about reality (Schein, 1990 Johnson et al., 2016; Wijethilake et al., 2021; Willis et al., 2016), but is understood to be more than just the sum of shared elements. Predominantly organizational culture shows emergent characteristics and a feed-forward and feedback loop from and back to the organization's members while further also being shaped by the past, symbols and rituals of the organization (Łukasik, 2018).

In other words, organizational culture could be understood as a shared coherent framework (between employees) supporting the trouble-free operation of an organization, while also shaping organizational and human behaviour through shared values and norms (Łukasik, 2018). This framework can as well be applied by the employees to identify possibilities and risks from changes within the company (Łukasik, 2018).

3.1.3. Culture change

As already demonstrated in the introduction organizational culture plays a major role in the transformation of organizations, as organizational change is significantly influenced by organizational culture (Wijethilake et al., 2021). This influence has been largely underestimated, which can in some cases lead to transitions failing due to organizational culture being left unmodified (Ojogiwa & Qwabe, 2021; Wijethilake et al., 2021).

Further, organizational culture change is notoriously difficult to achieve (Johnson et al., 2016; Łukasik, 2018) and can be a long-lasting multi-year effort (Limwichitr, Broady-Preston, & Ellis, 2015), as the internalisation of new organizational values takes time (Łukasik, 2018). Nonetheless, theoretical models regarding sustained cultural change have been developed and refined.

These models usually entail a three-step approach toward organizational cultural change, beginning with "unfreezing", the breaking of old behaviours and the fostering of awareness that change is needed. Following that, the "change or transformation state" takes place, in which processes and behaviours are experimented with and transformed. It is important in this stage to motivate people to use/internalize newly found processes and values. Lastly, the "freezing" stage takes place in which new behaviours and values are locked in (Johnson et al., 2016; Lewin, 1951; Weick & Quinn, 1999).

Cultural change can further be propagated through many ways, e.g., changing of organizational structures, different recruitment tactics, the establishment of new company guidelines, coaching, change of leadership(-style) etc. (Łukasik, 2018). It is recommended to use multiple approaches concurrently as this seems to be most effective in creating sustained cultural change (Johnson et al., 2016).

3.1.4. Constant learning culture

Vital parts of organizational change are the organizational as well as individual learning processes that facilitate the adaption of internal organizational processes. While learning by individuals is often encouraged in organizations and widespread knowledge collaboration would be highly beneficial to the organizations, organizations can be unable to take advantage of this benefit with an underdeveloped or flawed learning culture.

Therefore, organizations should aim to propagate and establish a constant learning culture within. Constant learning culture aims to provide an environment for sustained learning possibilities on both the personal and the organizational level by improving on two distinct building blocks for a constant learning culture and can be considered a practical implementation of critical thinking on an organizational level (Kucharska & Bedford, 2020).

Firstly, a positive learning climate needs to be established that supports self-development and growth as well as organizational development and growth. A shared knowledge culture and emphasis on collaboration here can positively influence learning culture, for example encouraging employees to take responsibility for learning and prioritizing heightened and honest communication (Rebelo & Gomes, 2011). This can further be facilitated by encouraging the personal development of the employees and encouraging creative and innovative solution-seeking (Kucharska & Bedford, 2020).

Equally important, a culture of mistake acceptance needs to be fostered, as an acknowledgement of mistakes is a necessary predecessor of true learning (Senge, 2006). Mistakes are necessary learning opportunities that will improve the overall processes over time rather than damaging them, by allowing people to leave their comfort zones and innovate on their processes (Rebelo & Gomes, 2011).

This can be promoted by encouragement towards a public declaration of mistakes to change the organizational attitude towards mistakes. However to ensure truthful reporting of mistakes, punishment when hidden mistakes are uncovered, might be necessary. Further mistakes, their origins and consequences should be reflected upon internally or discussed in a team or with a superior to formulate lessons learned and adjust one's conceptions (Kucharska & Bedford, 2020).

3.2. Transforming organizational culture and processes

3.2.1. Enabling change

In the first step of organizational cultural change, employees must be motivated to identify the current culture as a problem to create a basis for effective cultural change (Johnson et al., 2016; Ojogiwa & Qwabe, 2021). It is vital in this phase that employees are aware of the importance of the change, as the commitment of all members (employees) of the organization is necessary (Łukasik, 2018), as change needs to be on both individual and group levels (Limwichitr et al., 2015). Nonetheless, initial employee resistance can arise (Limwichitr et al., 2015; Ojogiwa & Qwabe, 2021; Wijethilake et al., 2021). This resistance to cultural change can stem from a perceived threat to an individual's status, identification and doubt in their professional work (Willis et al., 2016).

While in a system perspective, transition processes are emergent of the interplay of various actors pursuing their interests, the overall direction is usually driven and propagated by actors with a larger plan/vision (leaders) (Farla et al., 2012). Leadership's commitment and positive intent can significantly increase motivation and empowerment toward change in employees (Hornstein, 2015; Wijethilake et al., 2021) It is further important that organizational change is not just delegated to lower-level employees by executives and managers, as transformation is reached by full engagement of and direction by the leadership (Łukasik, 2018).

In short, this can be summarised as a transformational leader, identifying a need for change, creating and advertising a new vision and engaging their employees through inspirational influence (Burns, 1978), to establish the rationale for change that is needed to initiate the change process within the organization (Maes & Van Hootegem, 2019).

3.2.2. Transforming organizational processes and culture

In the following "transformation" phase of the process, the actual organizational transformational change occurs. This transformational change is characterised by the reshaping of strategies and behaviours as well as a shift of values and culture (Anderson & Anderson, 2002). Here the major challenge is the change of the underlying assumptions deriving from the old company culture (Limwichitr et al., 2015). It is usually facilitated by continuous training sessions and workshops (Johnson et al., 2016; Wijethilake et al., 2021).

The phase is further defined by a continuous feedback loop that exists between the behaviour of members of an organization and the organization itself, especially concerning shared assumptions (Łukasik, 2018). In the systems perspective, groups of individuals implicitly negotiate "programmes of action" to coordinate their actions and individual communicative events concerning sense-making/giving of individual agents can converge into a collective aim or programme (Hazy & Silberstang, 2009). The resulting actions by different individual actors, which can influence or reinforce, other actors' actions, then add together to create specific dynamics at the system level of complex systems (Farla et al., 2012). If a critical mass of adaption is reached on a local level an overall organizational transformation (change of system dynamics) can occur (Hazy & Silberstang, 2009). These system-level transformation process modifications then feedback and influence individual actors' perceived actions and strategies (Johnson et al., 2016). This feedback loop back to the staff during the change phase can increase new behaviour retention as positive feedback, in form of other employees transforming their tasks, can encourage employees to sustain changes (Hazy & Silberstang, 2009; Johnson et al., 2016).

3.3. Learning mechanisms

To facilitate a possible change of the prevalent (system-level) mechanisms and relations between the different actors and groups within the organization adaptation of the processes needs to be possible. This adaptation or modification can take place through various processes, however, in this study, we will focus on specific forms of learning, specifically multilevel organizational learning, dyad learning and learning from mistakes.

3.3.1. Feedback and feed forward learning in multilevel organizational learning

Organizational change is a dynamic and complex process based on interactions and propagation of information between the different levels of the organization. It can be divided into 2 main processes, feedforward learning, in which information & processes get propagated towards higher organizational levels, and feedback learning where changes on the organizational or team level get propagated back towards lower levels of the organization (Crossan, Lane, & White, 1999).

This type of learning is suggesting the existence of individual and shared mental models existing on the different levels of the organization. The individual will have their own representation of specific assumptions, be it a value or a task, in their personal mental model. Such mental models can be used to describe specific tasks that are performed within an organization, but other mental models can describe the patterns and assumptions underlying the organizational culture. The mental models of multiple individuals can then when aggregated create shared mental models on a team or group level. The aggregation of group-level mental models then is the basis for organizational-level mental representations, which represent the abstract understanding or established guidelines of a specific process or value of the whole organization (Canbaloğlu, Treur, & Wiewiora, 2022; Crossan et al., 1999).

A formalization of this type of feed-forward and feedback learning recently has been made in Canbaloğlu et al. (2021) and (Canbaloğlu et al., 2023a), and conceptualizes the process in 4 elements: the formation of mental models on the individual level, the transfer from the individual level to the organizational level through the creation of shared mental models, the maintenance and improvement of the mental model of organizational level and the backpropagation of organizational share mental models and knowledge to the individual incorporating these into their mental model (Canbaloğlu et al., 2021; Canbaloğlu et al., 2023a).

3.3.2. Dyad learning and learning from mistakes

Organizational learning however does not only happen on higher levels of abstraction but also takes place through the practice of coaching and mentoring. This form of learning is characterised by experienced people within an organization, directly teaching a task or the understanding of a process to less experienced people (Wiewiora, Chang, & Smidt, 2020). In this dyad learning mechanism, the mental models of the participating actors directly influence the opposing mental models, either in only one direction or in both directions, depending on the situation.

This form of learning further often takes place in the form of training sessions or discussions of previous work, allowing a reflection on one's assumptions and a transfer of individual and organizational level knowledge (Canbaloğlu et al., 2021), which offers a great opportunity to combine dyad learning in form of mentoring with the practice of learning from mistakes.

In an organizational environment that fosters the acceptance of mistakes learning from these can be facilitated and offers great value by helping the organization change and adapt more efficiently (Kucharska, 2021; Kucharska & Bedford, 2020). To allow this learning to happen, one needs to acknowledge that a mistake was made (Senge, 2006) and encourage an understanding that mistakes are part of human learning that allows us to restructure our processes, learn and adapt to change.

Acceptance and openness about mistakes are the first steps and initiators for scanning and interpretation of a mistake, or the suspected decision causing it (Mangels, Butterfield, Lamb, Good, & Dweck, 2006), which enables us to transform mistakes into newly acquired knowledge on individual and organizational levels (Kucharska & Bedford, 2020). This process however could not take place if mistakes are hidden, necessitating error reporting as an important step to enable learning from mistakes (Mohsin, Ibrahim, & Levine, 2019). Further positive or negative incentives, e.g. mandatory workshop attendance if a hidden error gets uncovered, might need to be considered to ensure sufficient levels of error reporting.

In the context of modelling this learning computationally or algorithmically these findings suggest a procedure containing multiple steps to be followed orderly to ensure learning from mistakes:

1. Observation or identification of a mistake occurring
2. Investigation if the mistake got hidden by the causing actor
   a. If a mistake was hidden positive incentives, e.g. workshops might be necessary
3. Open declaration of mistake
4. Analysis or Interpretation of mistake
   a. Either by self-reflection
   b. discussion with team members
   c. feedback from more experienced people
5. Incorporation of lessons into individual or organizational knowledge

A proposed computational modelling of this process can be found in part of the mechanisms of the presented computational model following.

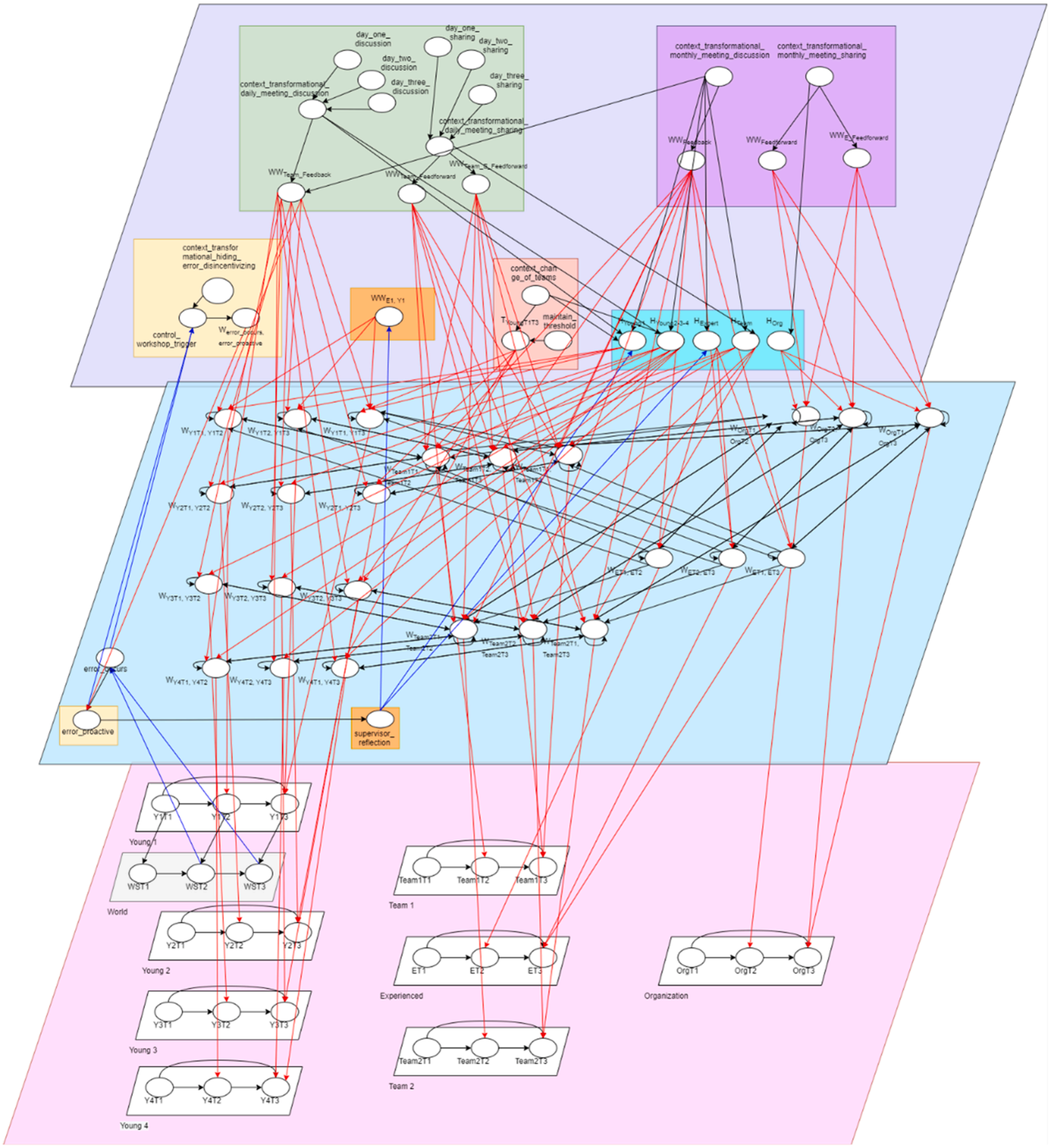

Fig. 1. Graphical Representation of the connectivity of the second-order adaptive network model: base-level mental states and mental models; the first-order self-model level for representations of weights of mental model connections (**W**-states) and inter mental model connections (connections between **W**-states); the second-order self-model for organizational/individual learning control mechanisms and supporting internal mechanisms.

4. Designing the dynamical systems model

4.1. Research focus

Given the wide scope of academic research into transformational organizational change, organizational culture and organizational learning mechanisms, a focus on specific aspects needs to be established. Therefore the created model and case scenario will concentrate on the following aspects of the previously established research:

- Confirming if the explored dynamic systems view of organizations (Farla et al., 2012; Hazy & Silberstang, 2009) can be translated into the self-modelling network modeling approach from (Treur (2020).
- Verifying if a shift in learning culture happens towards a constant learning culture (Kucharska, 2021)
- Exploring organizational learning mechanisms' effects and their effectiveness in correcting inaccurate mental models or organizational processes, in particular for:
  - o Feedback and Feed forward learning on both organizational and team levels (Crossan et al., 1999)
  - o Learning from Mistakes (Kucharska & Bedford, 2020) and Dyad Learning (Canbaloğlu et al., 2021)
  - o Leadership inspired/instructed (Łukasik, 2018) organizational culture change incentives e.g. workshops (Johnson et al., 2016; Wijethilake et al., 2021) or change of organizational structures (restructuring of teams)

4.2. Description of a case

To translate the findings from the academic literature into a coherent, dependable and practical model we will base the model on an

Table 1
Base level states of the introduced adaptive network model.

Nr	State	Explanation
X_1	Y1T1	Individual mental model state for Young Doctor 1 for task 1
X_2	Y1T2	Individual mental model state for Young Doctor 1 for task 2
X_3	Y1T3	Individual mental model state for Young Doctor 1 for task 3
X_4	Y2T1	Individual mental model state for Young Doctor 2 for task 1
X_5	Y2T2	Individual mental model state for Young Doctor 2 for task 2
X_6	Y2T3	Individual mental model state for Young Doctor 2 for task 3
X_7	Y3T1	Individual mental model state for Young Doctor 3 for task 1
X_8	Y3T2	Individual mental model state for Young Doctor 3 for task 2
X_9	Y3T3	Individual mental model state for Young Doctor 3 for task 3
X_{10}	Y4T1	Individual mental model state for Young Doctor 4 for task 1
X_{11}	Y4T2	Individual mental model state for Young Doctor 4 for task 1
X_{12}	Y4T3	Individual mental model state for Young Doctor 4 for task 1
X_{13}	Team1T1	Shared mental model state for Team 1 for task 1
X_{14}	Team1T2	Shared mental model state for Team 1 for task 2
X_{15}	Team1T3	Shared mental model state for Team 1 for task 3
X_{16}	Team2T1	Shared mental model state for Team 2 for task 1
X_{17}	Team2T2	Shared mental model state for Team 2 for task 2
X_{18}	Team2T3	Shared mental model state for Team 2 for task 3
X_{19}	ET1	Individual mental model state for Experienced Doctor for task 1
X_{20}	ET2	Individual mental model state for Experienced Doctor for task 2
X_{21}	ET3	Individual mental model state for Experienced Doctor for task 3
X_{22}	OrgT1	Shared mental model state for Organization for task 1
X_{23}	OrgT2	Shared mental model state for Organization for task 2
X_{24}	OrgT3	Shared mental model state for Organization for task 3
X_{25}	WST1	Task 1 executed in the world
X_{26}	WST2	Task 2 executed in the world
X_{27}	WST3	Task 3 executed in the world

Table 2
First-order self-model states of the introduced adaptive network model.

Nr	State	Explanation
X_{28}	$\mathbf{W}_{Y1T1,Y1T2}$	First-order self-model **W**-state for weight of the connection from Task 1 to Task 2 within the individual mental model of Young Doctor 1
X_{29}	$\mathbf{W}_{Y1T2,Y1T3}$	Y1 mental model connection weight **W**-state from task 1 to 2
X_{30}	$\mathbf{W}_{Y1T1,Y1T3}$	Y1 mental model connection weight **W**-state from task 1 to 3
X_{31}	$\mathbf{W}_{Y2T1,Y1T2}$	Y2 mental model connection weight **W**-state from task 1 to 2
X_{32}	$\mathbf{W}_{Y2T2,Y1T3}$	Y2 mental model connection weight **W**-state from task 2 to 3
X_{33}	$\mathbf{W}_{Y2T1,Y1T3}$	Y2 mental model connection weight **W**-state from task 1 to 3
X_{34}	$\mathbf{W}_{Y3T1,Y3T2}$	Y3 mental model connection weight **W**-state from task 1 to 2
X_{35}	$\mathbf{W}_{Y3T2,Y3T3}$	Y3 mental model connection weight **W**-state from task 2 to 3
X_{36}	$\mathbf{W}_{Y3T1,Y3T3}$	Y3 mental model connection weight **W**-state from task 1 to 3
X_{37}	$\mathbf{W}_{Y4T1,Y4T2}$	Y4 mental model connection weight **W**-state from task 1 to 2
X_{38}	$\mathbf{W}_{Y4T2,Y4T3}$	Y4 mental model connection weight **W**-state from task 2 to 3
X_{39}	$\mathbf{W}_{Y4T1,Y4T3}$	Y4 mental model connection weight **W**-state from task 1 to 3
X_{40}	$\mathbf{W}_{Team1T1,\ Team1T2}$	Team 1 mental model connection weight **W**-state from task 1 to 2
X_{41}	$\mathbf{W}_{Team1T2,\ Team1T3}$	Team 1 mental model connection weight **W**-state from task 2 to 3
X_{42}	$\mathbf{W}_{Team1T1,\ Team1T3}$	Team 1 mental model connection weight **W**-state from task 1 to 3
X_{43}	$\mathbf{W}_{Team2T1,\ Team2T2}$	Team 2 mental model connection weight **W**-state from task 1 to 2
X_{44}	$\mathbf{W}_{Team2T2,\ Team2T3}$	Team 2 mental model connection weight **W**-state from task 2 to 3
X_{45}	$\mathbf{W}_{Team2T1,\ Team2T3}$	Team 2 mental model connection weight **W**-state from task 1 to 3
X_{46}	$\mathbf{W}_{ET1,\ ET2}$	Experienced Doctor mental model connection weight **W**-state from task 1 to 2
X_{47}	$\mathbf{W}_{ET2,\ ET3}$	Experienced Doctor mental model connection weight **W**-state from task 2 to 3
X_{48}	$\mathbf{W}_{ET1,\ ET3}$	Experienced Doctor mental model connection weight **W**-state from task 1 to 3
X_{49}	$\mathbf{W}_{OrgT1,\ OrgT2}$	Organizational mental model connection weight **W**-state from task 1 to 2
X_{50}	$\mathbf{W}_{OrgT2,\ OrgT3}$	Organizational mental model connection weight **W**-state from task 2 to 3
X_{51}	$\mathbf{W}_{OrgT1,\ OrgT3}$	Organizational mental model connection weight **W**-state from task 1 to 3
X_{52}	error_occurs	Error detection control state
X_{53}	error_proactive	State representing error registration
X_{54}	supervisor_reflection	State representing triggering of supervisor reflection

applied case within the context of a medical institution, incorporating the found mechanisms into the greater context of the case. To achieve this we will employ the use of multi-level self-models within the model to create a second-order adaptive network model of the initiation and adaption phases of transformative organizational cultural change. The theoretical case the model is based on is created and confirmed by the collaboration of researchers from different disciplines (Wioleta Kucharska and Anna Wiewiora from Management and Business Science, Jan Treur from AI) and is described as follows:

(1) Edward – an authentic transformational leader focused on organizational constant improvement to secure a high level of performance (patient care). He wants to achieve it by creating a learning culture in which employees learn from each other.

(2) Edward believed that learning from mistakes is one of the best ways of creating a sustainable learning culture, as the acceptance of mistakes is a source of precious lessons and creates a better learning climate. It doesn't mean Edward tolerated the attitude of negligence. Edwards' intention was the avoidance of hiding mistakes. In his opinion hiding mistakes made harms patients and stopped learning. So, he was looking for a solution to keep high standards of healthcare.

(3) Edward implemented a set of organizational routines supporting his new strategy focused on the intellectual capital increase thanks to constant learning culture implementation

A) Edward introduced monthly obligatory meetings in which a senior staff was asked to present their own "precious mistakes made" in his/her career that gave him/her precious lessons and young doctors follow this practice. (creation of shared knowledge).

B) To the existing practice of discussing the most interesting, often successful cases, the presenting person obligatory also needed to add the presentation of "his/her recent lesson from a mistake." (dissemination of knowledge within the organization).

C) Edward introduced the principle that employees change shift teams every month to reduce focus on social experience and replace employees' focus on patients, learning and better dissemination of knowledge.

D) Edward introduced the obligatory registration of mistakes, admitting to them openly and proactively. After each shift, the most valuable lessons learned, from the mistakes that happened during the shift, were immediately discussed with the shift staff (experienced doctor) to correct misunderstandings and learn from mistakes.

E) If someone was caught hiding their mistakes, they have to attend an after-hours training and pay for it themselves. This should incentivise the doctors to not hide mistakes anymore and be proactive about them.

4.3. *The designed dynamical systems model*

Considering the case described above, an abstract approximation in the form of a computational dynamical systems model is created. It is greatly based on how organizational & individual learning mechanisms

Table 3
Second-order self-model states of the introduced adaptive network model.

Nr	State	Explanation
X_{55}	$\mathbf{H}_{Young1}$	Speed state for Young Doctor 1 first-order self-model **W**-states
X_{56}	$\mathbf{H}_{Young2\text{-}3\text{-}4}$	Speed state for Young Doctor 2, 3, 4 first-order self-model **W**-states
X_{57}	$\mathbf{H}_{Expert}$	Speed state for Experienced Doctor first-order self-model **W**-states
X_{58}	$\mathbf{H}_{Team}$	Speed state for Team first-order self-model **W**-states
X_{59}	$\mathbf{H}_{Org}$	Speed state for Organization first-order self-model **W**-states
X_{60}	context_transformational_hiding_error_workshop	Context state triggering workshop mechanism
X_{61}	control_workshop_trigger	Detection state triggering a workshop if non-registration of mistake is detected
X_{62}	$\mathbf{WW}_{error\_occurs,\ error\_proactive}$	Connection weight from error_occurs to error_proactive
X_{63}	$\mathbf{WW}_{E,\ Y1}$	Connection weight from Experienced Doctors to Young Doctors 1 **W**-states
X_{64}	context_transformational_monhtly_ meeting_sharing	Context state triggering monthly meeting feedforward learning
X_{65}	$\mathbf{WW}_{Feedforward}$	Connection weight for feedforward learning (team => org **W**-states)
X_{66}	$\mathbf{WW}_{E\_Feedforward}$	Connection weight for feedforward learning (experienced => org **W**-states)
X_{67}	context_transformational_monhtly_ meeting_discussion	Context state triggering monthly meeting feedback learning
X_{68}	$\mathbf{WW}_{Feedback}$	Connection weight for feedforward learning (org => team **W**-states)
X_{69}	control_change_of_teams	Context state triggering shuffling of teams
X_{70}	$\mathbf{T}_{YoungT1T3}$	Threshold state for T1 => T3 **W**-states of Young Doctors
X_{71}	maintain_threshold	Internal support state to maintain threshold
X_{72}	context_transformational_daily_ meeting_sharing	Context state triggering daily meeting feedforward learning
X_{73}	$\mathbf{WW}_{team\_Feedforward}$	Connection weight for feedforward learning (young => team **W**-states)
X_{74}	$\mathbf{WW}_{team\_E\_Feedforward}$	Connection weight for feedforward learning (experienced => team **W**-states)
X_{75}	context_transformational_daily_ meeting_discussion	Context state triggering daily meeting feedback learning
X_{76}	$\mathbf{WW}_{team\_feedback}$	Connection weight for feedforward learning (team => young **W**-states)
X_{77}	day_one_sharing	Context state triggering day 1 sharing
X_{78}	day_two_sharing	Context state triggering day 2 sharing
X_{79}	day_three_sharing	Context state triggering day 3 sharing
X_{80}	day_one_discussion	Context state triggering day 1 discussion
X_{81}	day_two_discussion	Context state triggering day 2 discussion
X_{82}	day_three_discussion	Context state triggering day 3 discussion

controlled by the organizational culture influence the mental model representations, illustrated for a simple 3-step healthcare-related task, on the individual, team and organizational level. This 3-step task is used as an abstraction and could be replaced by any task in which it is of utmost importance that step 1 is followed by step 2 being followed by step 3. This model deals with repairing a faulty mental representation of said task, which would lead to a young doctor, skipping one of these steps. The designed computational network model created on this basis is depicted in 3D according to three levels in Fig. 1. For an extensive explanation of the different states, an overview can be found in Tables 1–3 for the three levels, respectively. The base level (pink lower plane in Fig. 1), is the undermost level. It represents the mental models of the aforementioned 3-step process of different entities within different organizational levels (individual, group, organization) of an organization (Canbaloğlu et al., 2021, 2023a; Canbaloğlu et al., 2023b). The 3 states in each mental model e.g. Y1T1, Y1T2, and Y1T3, represent as aforementioned an understanding of a 3-step healthcare-related task, that needs to be followed in succession.

However, as visible by the connections between the states, it can be possible for the mental models to be faulty, which would lead to Task 2 getting skipped. In this case, Task 1 would have a strong connection to Task 3 and would not trigger Task 2. Further, the base level depicts mental models on different levels of the organization, namely:

- **Young 1 – 4**

Four young doctors' understanding of the task. Each doctor can have a different understanding and therefore different mental model of the task.

- **Team 1 – 2**

The shared understanding of the task within a team by a shared mental model. Two shift teams exist in this model, each consisting of 2 young doctors.

- **Experienced**

An experienced doctor who will act as the supervisor of the young doctors. His mental model, given his experience, is next to a perfect representation of the task.

- **Organization**

The understanding of the task on the organizational level.

- **WST 1–3**

The world states, the states representing the actual real-world tasks occurring. These are the states in which the error detection mechanism detects mistakes.

Above the base level, the first-order self-model level (blue middle plane in Fig. 1) reflects the adaptiveness of the mental models of the base plane. This plane is characterised by the **W**-states, grouped in triads in this model, which represent the adaptive weights for the connectivity

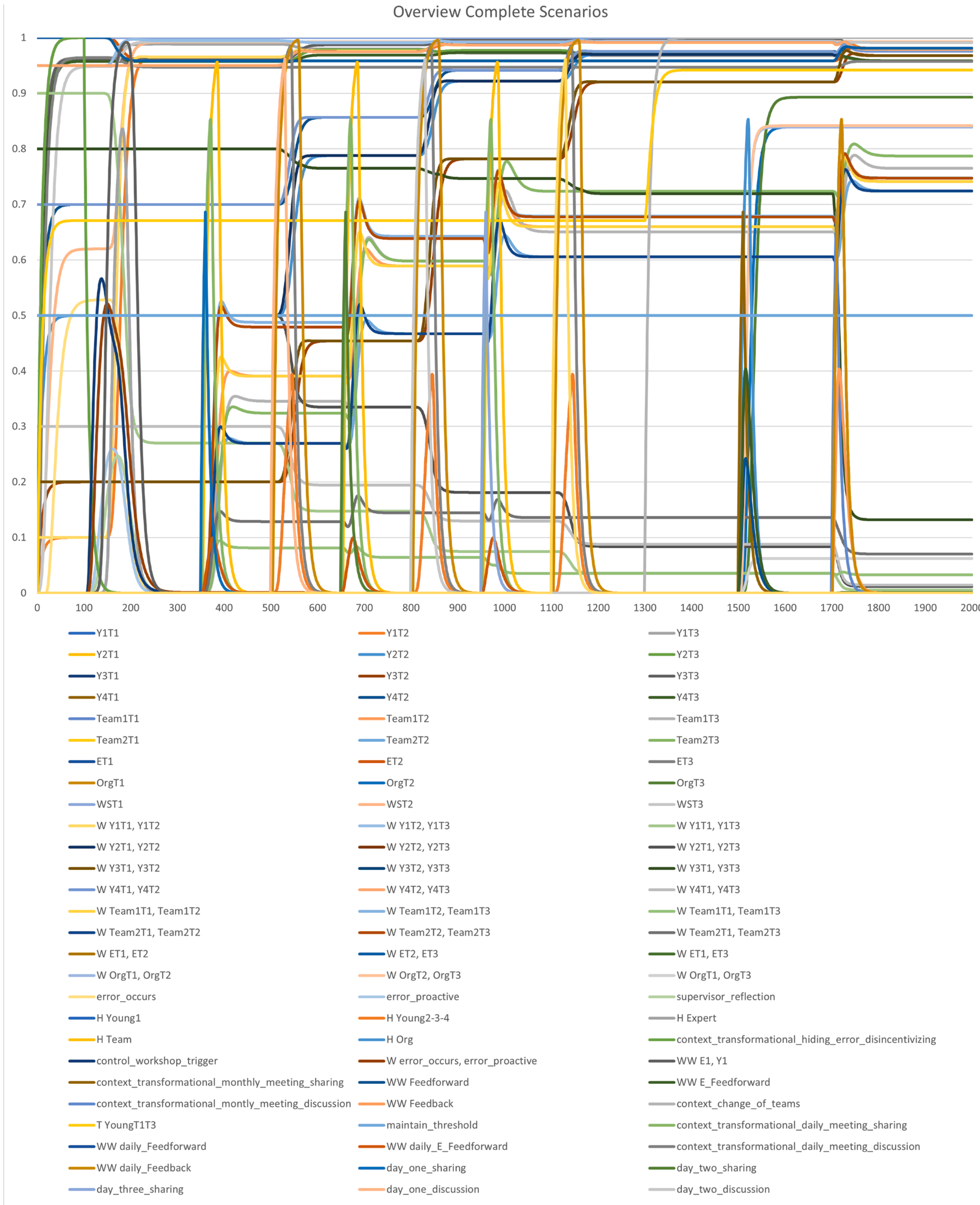

Fig. 2. Simulation Graph showing a full overview of the scenario and all states.

between the states of the mental models of the different entities of the organization (young doctors, experienced doctor, teams, organization).

There further exist same-level connections between some of the **W**-states, providing the possibility for either feed-forward learning, feedback learning (Canbaloğlu et al., 2021, 2023a; Canbaloğlu et al., 2023b), dyad learning (e.g., cooperation, mentoring) (Wiewiora et al., 2020) or learning from mistakes (Kucharska, 2021; Kucharska & Bedford, 2020). These connections either enable the creation of new shared mental models, the adaptation of shared or individual models or the correction of faulty mental models.

The further states in this plane are parts of some of the learning or detection mechanisms otherwise depicted in the uppermost plane. The "error_occurs" state detects if a mistake happens in the real-world task (world states). The "error_proactive" state, determines if the mistake that happened gets registered/openly proclaimed. The "supervisor_reflection" state gets triggered as a result of the young doctor being proactive about an error and triggers the"Learning from Mistakes" mechanism.

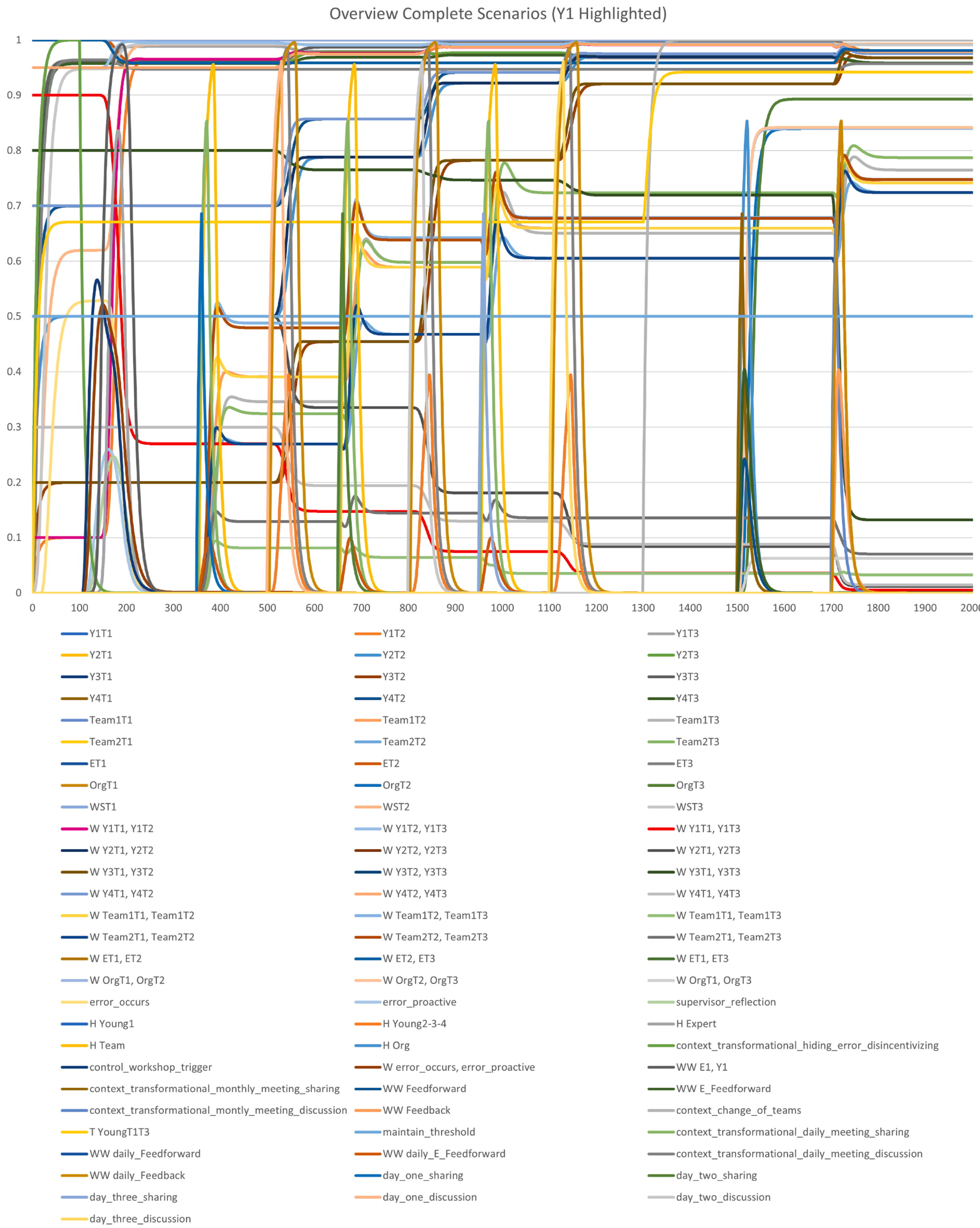

Fig. 3. Simulation Graph showing a full overview of the scenario and all states with $\mathbf{W}_{Y1T1,Y1T3}$ and $\mathbf{W}_{Y1T1,Y1T2}$ highlighted.

In the second-order self-model level (purple upper plane in Fig. 1), some context-sensitive control mechanisms necessary for the learning mechanisms, are situated. For a better understanding of the model, each mechanism's states are highlighted according to the mechanisms they belong to:

- The **yellow** highlighted states depict the mistake registration mechanism, as well as a control state detecting nonregistered mistakes, which triggers the mechanisms (after-hours training) taken by the organization to incentivise the young doctors not to hide mistakes. If a mistake gets registered by the doctor this last incentivising mechanism is not triggered. The context of the transformational leader establishing the mistake management system is depicted in a state there as well (Kucharska, 2021).
- The **orange** highlighted states, portray the triggering and implementation of the "Learning from Mistakes" mechanism. Here the "supervisor_reflection" state triggers the analysis and discussion of the mistake. This analysis and discussion take place in form of dyad

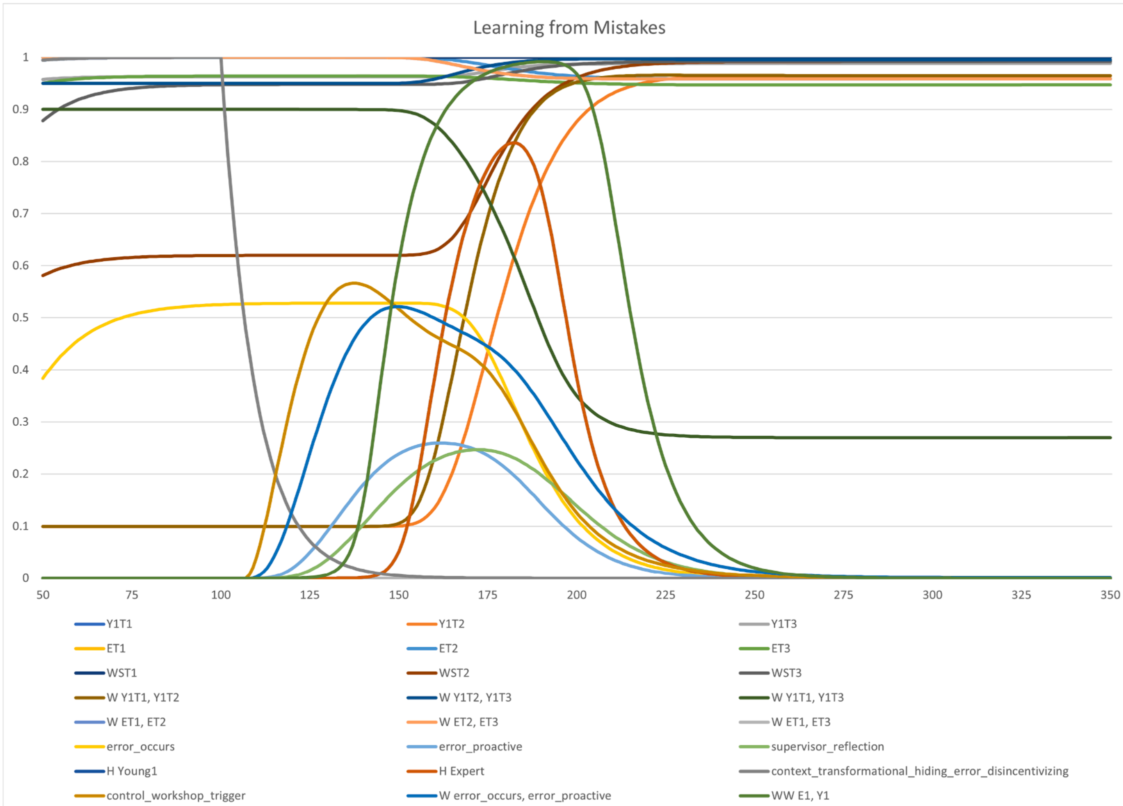

Fig. 4. Simulation Graph showing "Learning from Mistakes" Phase of Simulation and related states.

learning or mentorship by the experienced doctor toward the young doctor (Mangels et al., 2006).

- The **green** highlighted states represent the daily shift closing meetings and their triggering by context states. These meetings are divided into 2 different phases.
  - o First is the sharing phase, representing the sharing of mistakes and experiences during the previous shift. This triggers feedforward learning, which creates or adapts shared mental models on the team level. It is the first step in organizational learning.
  - o Secondly, the discussion phase gets triggered, in which the lessons learned from that mistake are formulated. This leads to learning and adjustments of understanding on the individual (young doctors level), which is modelled by feedback learning and represent the dissemination of knowledge
- The **purple** highlighted states relate to the monthly meetings in which experienced and young doctors share and discuss their most important learning experiences and mistakes of the past. Here, the sharing phase triggers feedforward learning to create a shared organizational-level mental model. In the discussion phase, the knowledge is then passed down to all the organizational levels, leading to adjustments of the mental models and their corresponding weights.
- The **red** highlighted states model the influence of young doctors changing or shuffling their teams. The increased focus of the doctors on work is represented here by a change in some of their threshold states. This change in thresholds for some of their states enables them to be more open to learning from each other via the shared mental models.
- The **turquoise** highlighted states are part of an internal control mechanism, that controls some of the model's behaviours, and ensures the simulations run correctly and smoothly.

Overall the model aims at conceptualizing and modeling transformational organizational change, in the context of learning from mistakes and a change in organizational culture. A culture in which mistakes aren't shared and hidden is transformed into a culture with an emphasis on constant learning, safety culture and collaboration. This is facilitated by several changes in the existing organizational processes or by added mechanisms, which enable and create a critical reflection on all organizational levels (individual, team, organizational).

5. Simulation results

This section will discuss the simulation results of the model that was created based on the aforementioned case and described in the previous section.

5.1. Full scenario

In Fig. 2 a full scenario with all its states is shown. Fig. 3 shows highlighted **W**-states for learnt connections of Young Doctor 1. The simulation starts with the visible formation of the mental models of the Young Doctors 1 to 4 (Y1 – Y4) and Expert (E) from Time 0 to 50.

At around 100 the transformational leader puts mistake registration and disciplinary workshops in place (context_transformational_hiding_error_disincentivizing), aiming to increase the chance of the young doctor to be proactive about (registering) his mistake.

This triggers the activation of the 'Learning from Mistakes' mechanism which takes place between 100 and 300. Following the modelling of 3 days and the respective daily closing shift meeting are modelled. This phase begins at 350 and finishes around 250. Each day's closing shift meeting is signified by 2 different sub-phases, the sharing of mistakes of that day modelled by feedforward learning leading to the creation or adaption of shared team mental models, as well as the discussion of said mistake and the takeaway lesson learned from it, which is modelled by feedback learning and the adaption of the young doctors' mental model representations. At around 1300 the "change of

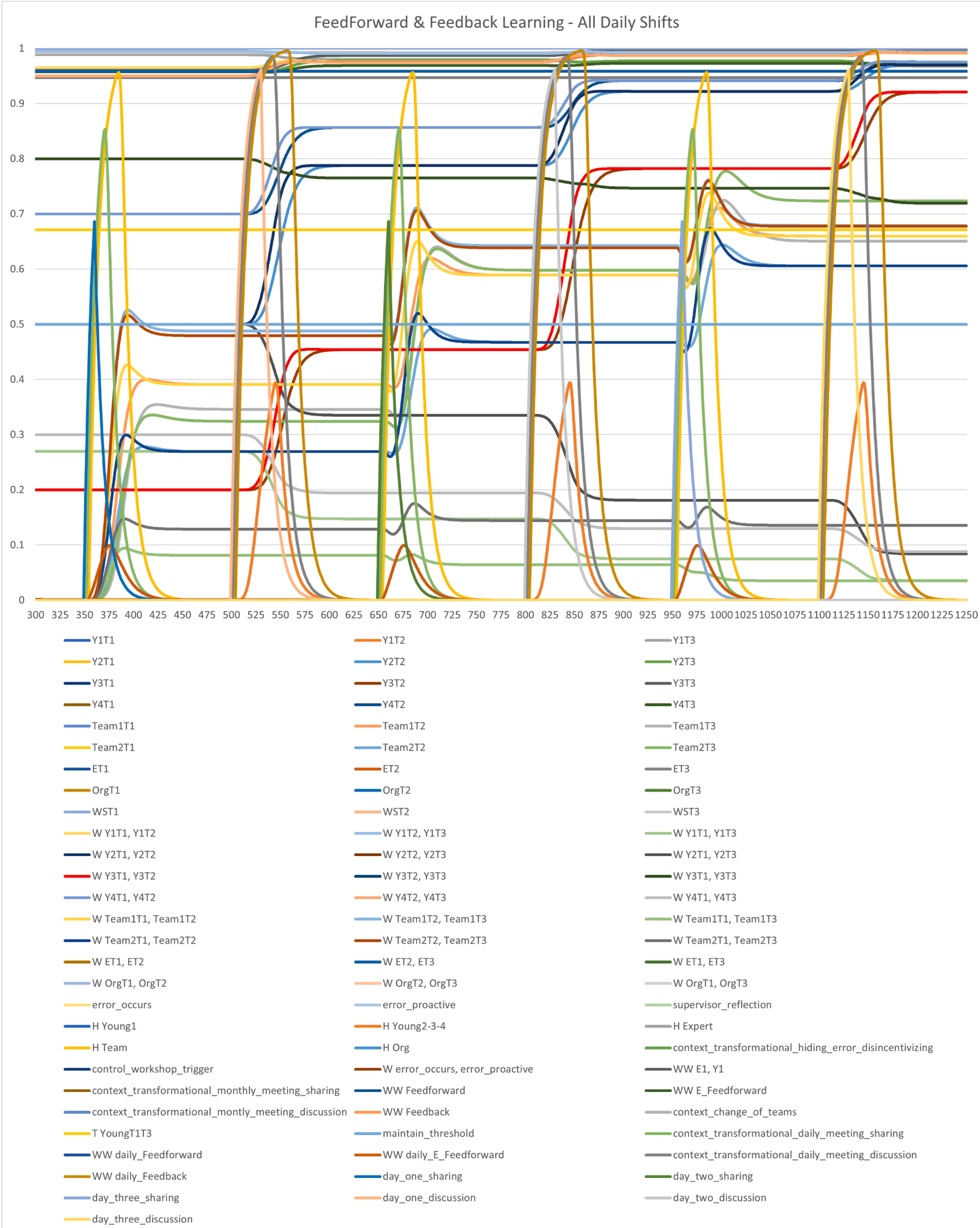

Fig. 5. Simulation Graph showing complete 'Daily Shifts reflection' Phase of simulation and all states.

teams" is modelled, which has a direct influence on the young doctors' thresholds $\mathbf{T}_{\mathrm{YoungT1T3}}$ by increasing the said threshold, therefore increasing their ability to focus on their work and enable better learning.

From 1500 to 1600 the first phase of the monthly shift meeting takes place, with every doctor recapping the last month and sharing their most precious mistake made in their career. In this phase, a shared organizational level mental model is created, via feedforward learning, based on the lower-level organization mental models. From 1700 till 1800 the second phase of the monthly meetings takes place, in which the mistakes are discussed, and the lessons learned from said mistakes are disseminated within the organization via feedback learning and the adaption of lower-level mental models.

Overall, we can observe in the results of the simulations that the changes made to the prevailing organizational processes, led to a shift in learning culture enabling and triggering constant learning opportunities and incentives for the employees, which results in corrected mental

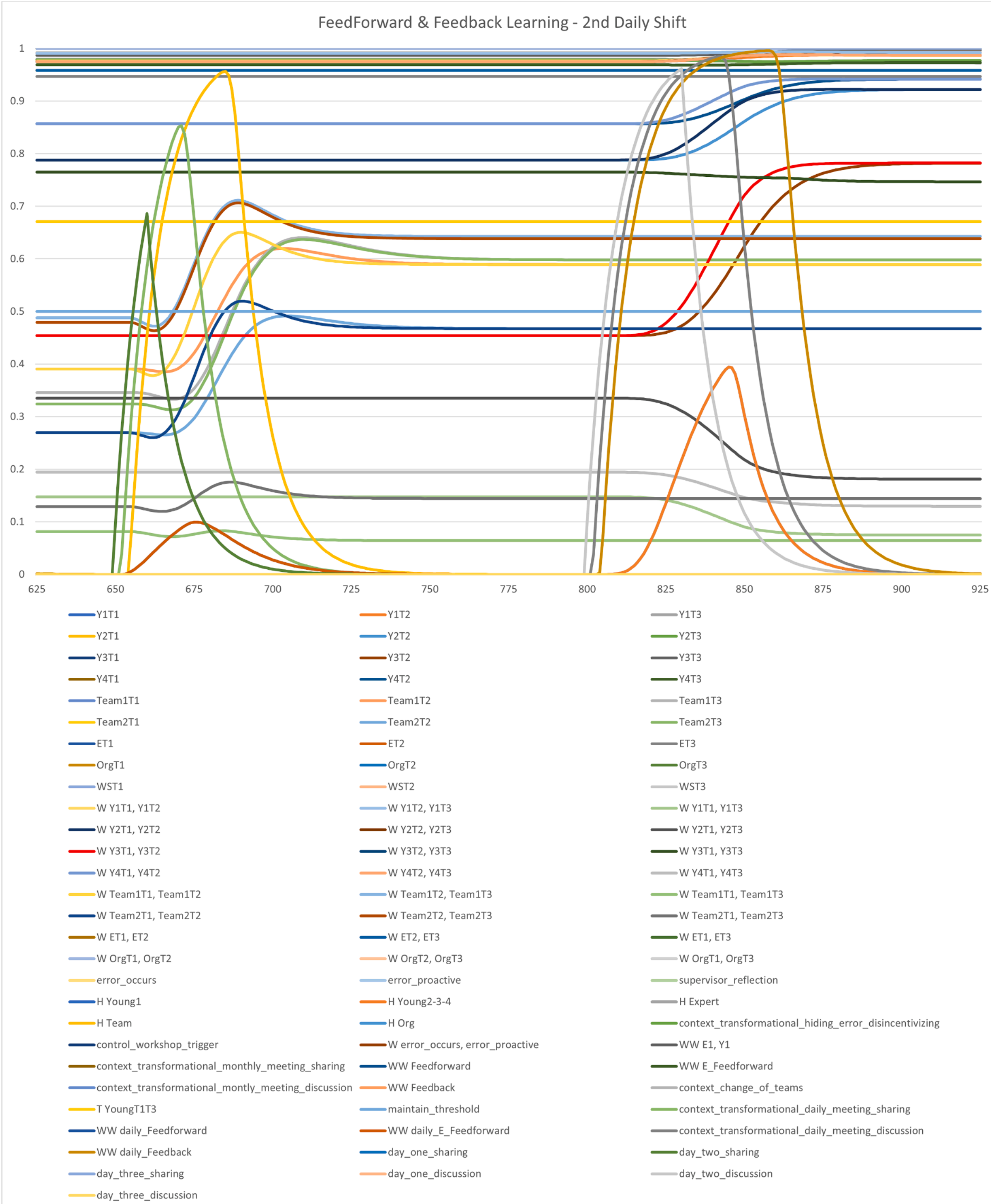

Fig. 6. Simulation Graph showing '2nd Daily Shifts reflection' of simulation and all states.

models representing a correct understanding of the succession of task on all organizational levels.

5.2. *Learning from mistakes*

As observable in Fig. 4, the learning from mistakes in this simulation starts with the transformational leader enabling the mistake/error registration and workshops, at around 100.

Although already before this activation the observation state "error_occurs" gets activated by the world states, as WST2 is too low and doesn't get fully activated, signifying that an error in the process occurs. Theoretically, if the young doctor is proactive about his mistake and registered it, the state "error_proactive" would be activated as well. However, at the beginning of the simulation, the young doctor doesn't register his mistake and hides them. This is registered by the "control_workshop_trigger" state around 130, which activates a correction mechanism by making the young doctor attend a workshop on error handling which leads to an increase in them being proactive about their mistake and registering it at around 150 (by increasing $\mathbf{W}_{\text{error\_occurs, error\_proactive}}$) (Kucharska, 2021). Registering the mistake and with this

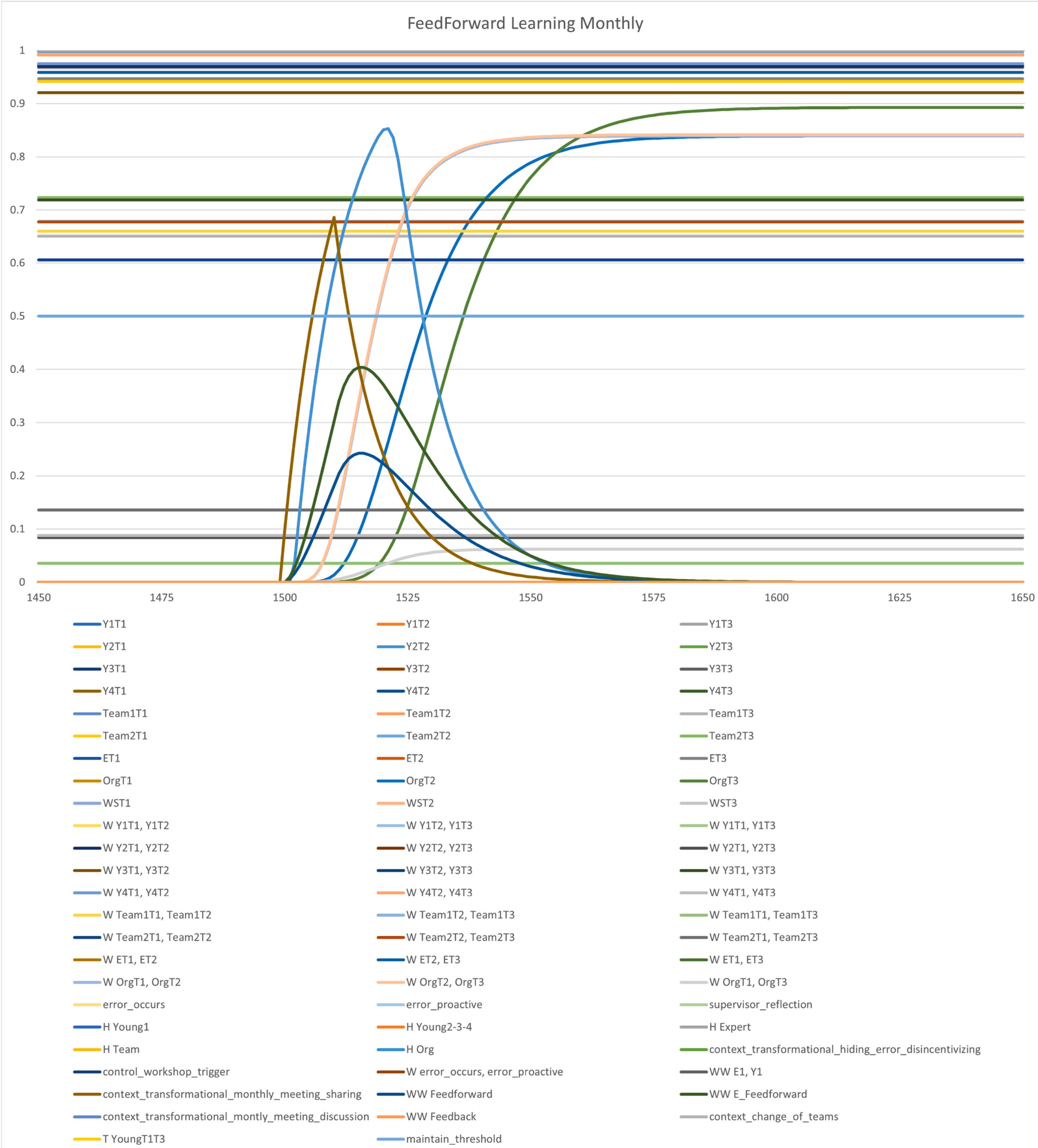

Fig. 7. Simulation Graphs showing the 'Feedforward & Feedback Learning' phase of the simulation and all states.

the doctor openly admitting to his mistake is the first important step in this process as it enables them to analyse and learn from the mistake, confirming and approximating behaviour that was validated in previous studies (Senge, 2006).

The registration of the mistake activates the analysis and reflection phase of this process, by activating the "supervisor_reflection" state at 175, which triggers the dyad learning and mentorship learning between the experienced doctor (E) and the young doctor (Y1). This corrects the young doctor's understanding of the task, by influencing the weights that create his mental model representation ($\mathbf{W}_{Y1T1,Y1T2}$; $\mathbf{W}_{Y1T2,Y1T3}$; $\mathbf{W}_{Y1T1,Y1T3}$), as visible between 150 and 225. After this learning has taken place, and the mental model of the young doctor is corrected, the real-world state WST2 gets activated to the necessary extent, which signals that the mistake doesn't occur anymore. This confirms literature findings in which a reflection upon mistakes leads to correct knowledge representation (Kucharska & Bedford, 2020). If no mistake is occurring anymore the "learning from mistakes" mechanism shuts itself down, without outside influence. However, if the mental representation of the young doctor would be incorrect again, the mechanism would be triggered again via the world states.

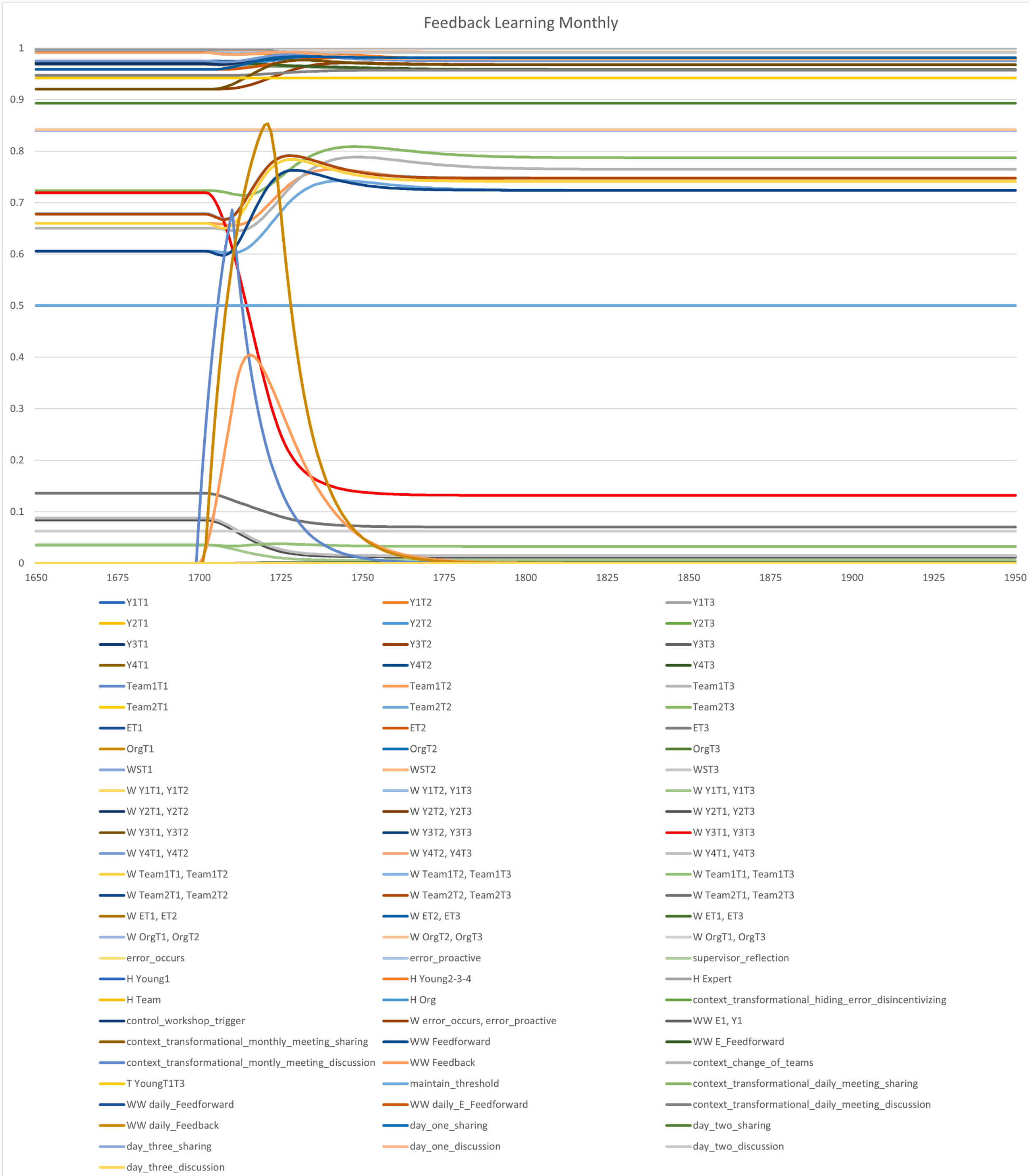

Fig. 7. (*continued*).

5.3. Daily shift reflections

Next in the simulation, the modelling of 3 days of shift closing reflections takes place, as shown in Fig. 5.

Each day's reflection starts with the sharing of the mistakes that have happened and a recap of the last shift (feedforward learning), here at 350, 650 and 950, followed by a formulation of lessons learned (feedback learning), here at 500, 800 and 1100. As evident by the highlighted red line showing the value for $\mathbf{W}_{Y3T1,Y3T2}$ (the mental connection for the third young doctor between tasks 1 and 2) the daily shift meetings positively influence and adapt the young doctors' mental representations towards a more correct understanding of the task. While in the beginning, he did not believe in Task 2 following Task 1, with only a value for this connection of 0.2, he does believe in this connection after 3 days of end-of-shift reflections, shown by the connection value now being around 0.9. This is expected behaviour when referencing it with the found literature, as it proves that learning from mistakes in a context of a constant learning culture enabling organizational learning, proves effective (Canbaloğlu et al., 2021; Canbaloğlu et al., 2023a; Kucharska, 2021; Kucharska & Bedford, 2020).

If we observe the shift meeting closer, by focusing e.g., on the second shift closing meeting we can observe some further behaviour. As Fig. 6 shows, the division of the process into 2 subphases is clear.

First, between 650 and 725, the sharing part of the meeting takes

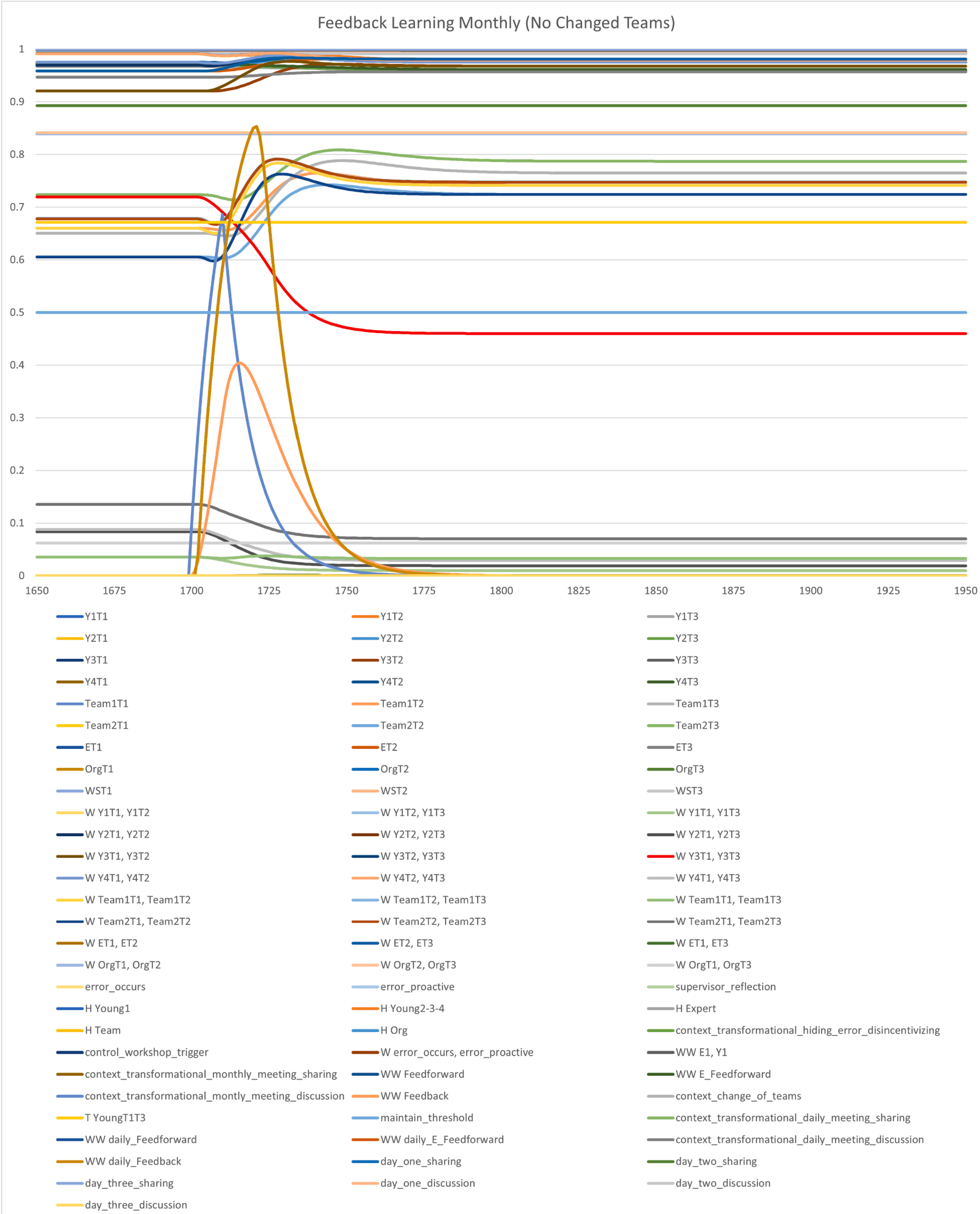

Fig. 8. Simulation Graphs showing the 'Feedback Learning' phase of simulation and all states with the variation of no change of teams being triggered.

place. Here it is visible how the shared mental models on the team level are formulated further. After they were already established to an extent in the first shift meeting the second shift meeting increases the clarity of the team levels' mental representation. Once the first phase of the meetings, the sharing, has finished, the second phase of the meetings gets triggered after a short delay. This phase starts at 800 and extends until 900. It is characterized by a team reflection happening and the formulation of lessons learned that are then disseminated to the doctors who adapt their mental representations based on the lesson, evident for example by the red highlighted line representing the mental representation of the connection's strength between task 1 and 2 of Young Doctor 3. This process of the formulation of shared mental models and their subsequent influence on the lower-level mental models is known as feed-forward and feedback learning as defined by Crossan et al. (1999), and

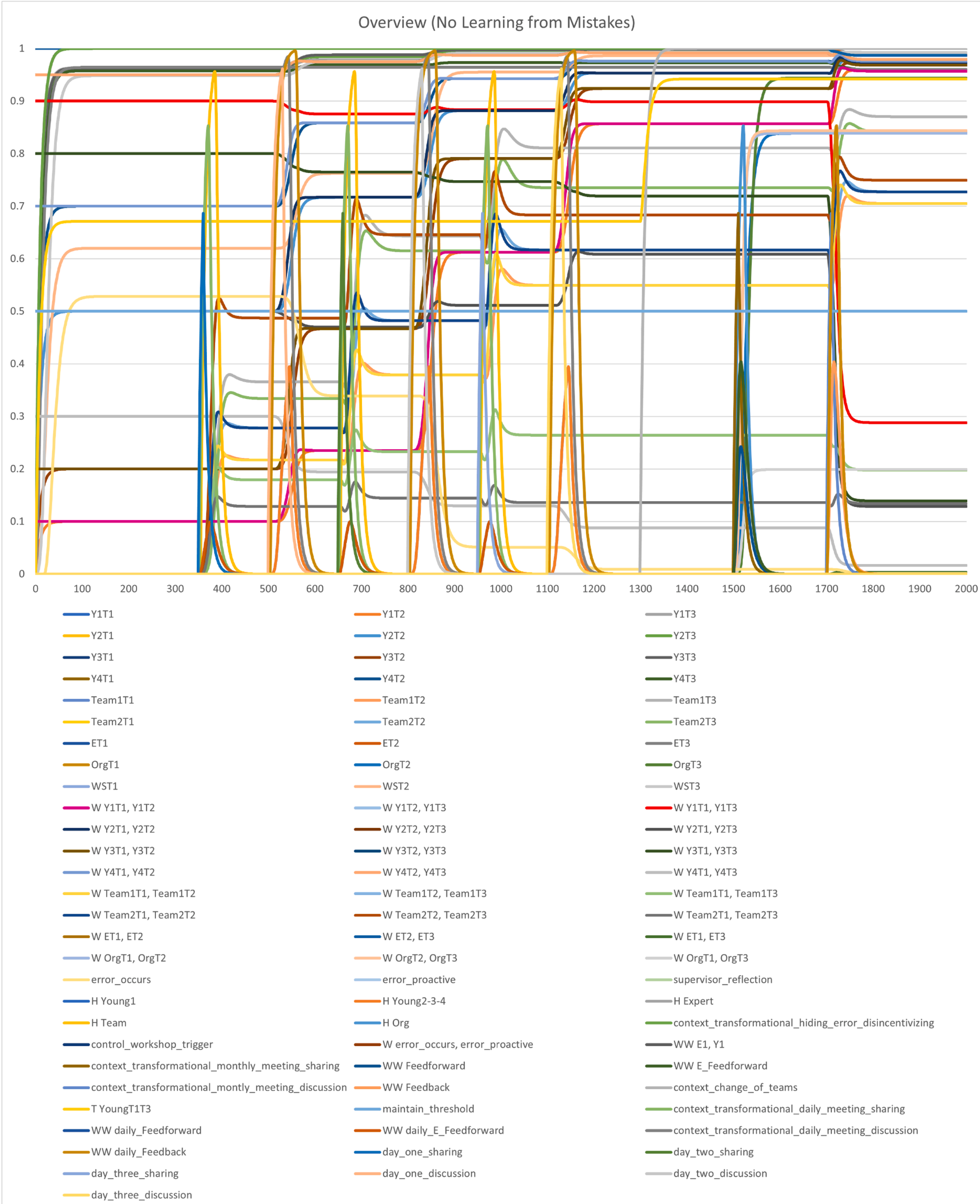

Fig. 9. Simulation Graph showing a full overview of the scenario and all states without triggering of 'Learning From Mistakes' mechanism.

functions as expected and theorized in other related work (Canbaloğlu et al., 2021, 2023a; Canbaloğlu et al., 2022).

5.4. *Monthly shift reflections & change of teams*

The next phase of the simulation is characterised by the occurrence of the monthly organizational meeting, in which the whole organization and all doctors meet up. It is necessary to mention that previous to this meeting at the time of 1300 the "changing of teams" occurred. The simulation tries to approximate the effects of a shuffling of the teams of the young doctors, which directs their focus away from socializing back to their work, by adapting their thresholds to learning. As visible in Fig. 1 at 1300 this is modelled by an increase in the adaptive threshold of the young doctors represented by $\mathbf{T}_{\mathrm{YoungT1T3}}$.

Following this, the monthly meeting begins to take place at 1500, characterized by the formation of an organizational level shared mental model) via propagation and aggregation of their specific weight states. This represents the doctors, especially also the experienced doctors sharing their most precious mistakes made in their career. At the time of 1700, the second part of this process commences in which the panel

Table 4
Base connectivity for the base level states.

mb	base connectivity	1	2	3	4	5
X_1	Y1T1	X_1				
X_2	Y1T2	X_1				
X_3	Y1T3	X_2	X_1			
X_4	Y2T1	X_4				
X_5	Y2T2	X_4				
X_6	Y2T3	X_5	X_4			
X_7	Y3T1	X_7				
X_8	Y3T2	X_7				
X_9	Y3T3	X_8	X_7			
X_{10}	Y4T1	X_{10}				
X_{11}	Y4T2	X_{10}				
X_{12}	Y4T3	X_{11}	X_{10}			
X_{13}	Team1T1	X_{13}				
X_{14}	Team1T2	X_{13}				
X_{15}	Team1T3	X_{14}	X_{13}			
X_{16}	Team2T1	X_{16}				
X_{17}	Team2T2	X_{16}				
X_{18}	Team2T3	X_{17}	X_{16}			
X_{19}	ET1	X_{19}				
X_{20}	ET2	X_{19}				
X_{21}	ET3	X_{20}	X_{19}			
X_{22}	OrgT1	X_{22}				
X_{23}	OrgT2	X_{22}				
X_{24}	OrgT3	X_{23}	X_{22}			
X_{25}	WST1	X_1				
X_{26}	WST2	X_{25}	X_2			
X_{27}	WST3	X_{26}	X_3			

Table 5
Base connectivity for the first-order self-model states.

mb	base connectivity					
X_{28}	$\mathbf{W}_{Y1T1,Y1T2}$	X_{40}	X_{46}	X_{28}		
X_{29}	$\mathbf{W}_{Y1T2,Y1T3}$	X_{41}	X_{47}	X_{29}		
X_{30}	$\mathbf{W}_{Y1T1,Y1T3}$	X_{42}	X_{48}	X_{30}		
X_{31}	$\mathbf{W}_{Y2T1,Y1T2}$	X_{40}	X_{31}			
X_{32}	$\mathbf{W}_{Y2T2,Y1T3}$	X_{41}	X_{32}			
X_{33}	$\mathbf{W}_{Y2T1,Y1T3}$	X_{42}	X_{33}			
X_{34}	$\mathbf{W}_{Y3T1,Y3T2}$	X_{43}	X_{34}			
X_{35}	$\mathbf{W}_{Y3T2,Y3T3}$	X_{44}	X_{35}			
X_{36}	$\mathbf{W}_{Y3T1,Y3T3}$	X_{45}	X_{36}			
X_{37}	$\mathbf{W}_{Y4T1,Y4T2}$	X_{43}	X_{37}			
X_{38}	$\mathbf{W}_{Y4T2,Y4T3}$	X_{44}	X_{38}			
X_{39}	$\mathbf{W}_{Y4T1,Y4T3}$	X_{45}	X_{39}			
X_{40}	$\mathbf{W}_{Team1T1,\ Team1T2}$	X_{49}	X_{28}	X_{31}	X_{40}	X_{46}
X_{41}	$\mathbf{W}_{Team1T2,\ Team1T3}$	X_{50}	X_{29}	X_{32}	X_{41}	X_{47}
X_{42}	$\mathbf{W}_{Team1T1,\ Team1T3}$	X_{51}	X_{30}	X_{33}	X_{42}	X_{48}
X_{43}	$\mathbf{W}_{Team2T1,\ Team2T2}$	X_{49}	X_{34}	X_{37}	X_{43}	X_{46}
X_{44}	$\mathbf{W}_{Team2T2,\ Team2T3}$	X_{50}	X_{35}	X_{38}	X_{44}	X_{47}
X_{45}	$\mathbf{W}_{Team2T1,\ Team2T3}$	X_{51}	X_{36}	X_{39}	X_{45}	X_{48}
X_{46}	$\mathbf{W}_{ET1,\ ET2}$	X_{49}	X_{46}			
X_{47}	$\mathbf{W}_{ET2,\ ET3}$	X_{50}	X_{47}			
X_{48}	$\mathbf{W}_{ET1,\ ET3}$	X_{51}	X_{48}			
X_{49}	$\mathbf{W}_{OrgT1,\ OrgT2}$	X_{40}	X_{43}	X_{46}	X_{49}	
X_{50}	$\mathbf{W}_{OrgT2,\ OrgT3}$	X_{41}	X_{44}	X_{47}	X_{50}	
X_{51}	$\mathbf{W}_{OrgT1,\ OrgT3}$	X_{42}	X_{45}	X_{48}	X_{51}	
X_{52}	error_occurs	X_{26}	X_{27}			
X_{53}	error_proactive	X_{52}				
X_{54}	supervisor_reflection	X_{71}				

discusses the cases, and integrates the lessons learned from the "precious" mistakes shared by the doctors. This leads to organizational learning throughout all organizational levels in the form of feedback learning. As expected this results in a correction of the mental models on the different organizational levels. An example can be seen in the red highlighted line in the right part of Fig. 7 which shows how young doctor 3 unlearns the wrong association between task 1 and task 3 ($\mathbf{W}_{Y3T1,Y3T2}$), visible by the decrease of its value from around 0.7 to 0.2. (Canbaloğlu et al., 2021; Crossan et al., 1999).

5.5. Scenario variations

To observe some of the influences that the different mechanisms have in interconnection to the overall simulation 2 variations to the scenario were implemented. First, we wanted to observe what difference a change of teams made to the dissemination of lessons learned within the process of organizational learning in form of feedforward and feedback learning.

The result of this change can be seen in Fig. 8. Here especially the red highlighted line is again of interest. It represents the same state highlighted in Fig. 9 and shows a significantly less pronounced learning effect than previously. We can observe that the increased threshold for the young doctors had a significant influence on their ability to correct their mental models as a previous decrease of the strength of the wrong connection of tasks by 0.5 points is now reduced to only a correction by 0.2 points. Proving that a change of teams and the subsequently increased focus by the doctors on their work has significant effects.

Another variation that was made to the simulation was the deactivation of the 'learning form mistake' mechanism, to observe the difference it made for young doctor 1 to have them learn from their mistakes at the beginning of the simulation. In Fig. 9 the overview of the simulation is shown in which no learning from mistakes has occurred. Highlighted in the figure in red is the state $\mathbf{W}_{Y1T1,Y1T3}$ representing the connection that skips a task, leading to a mistake, and in purple/pink $\mathbf{W}_{Y1T1,Y1T2}$ which represents the correct succession of task after task 1.

As observable in Fig. 3, the values for both highlighted lines are quickly reaching close to their ideal values. For $\mathbf{W}_{Y1T1,Y1T3}$ that is reaching a value of 0, representing complete disbelief in the wrong succession of tasks and for $\mathbf{W}_{Y1T1,Y1T2}$ that is reaching close to 1, representing a correct understanding of the succession of tasks. In contrast to that in Fig. 9 it is visible that the correction of the mental representation of the succession of tasks does not occur to the same extent. For $\mathbf{W}_{Y1T1,Y1T3}$ for example we can observe that the correction only happens significantly when the monthly meeting and with that full organizational learning occurs. For $\mathbf{W}_{Y1T1,\ Y1T2}$ while we still see a correction to the same extent as in Fig. 3 happens, without the learning from mistakes, in the beginning, this learning effect required the full time and mechanisms of the simulation.

These observations conclude that learning from mistakes is a powerful mechanism in the correction of faulty mental models, and has a significant influence, but also that the further organizational learning mechanisms are equally powerful in ushering adaptation and correction of mental representation in individuals.

6. Discussion & conclusion

This paper was based on material from (Rass et al., 2022). The goal of this research was to further explore the field of transformational change, in the context of organizational learning and culture by computational modelling of organizational and individual processes. This specifically realizes itself in the objective to create an adaptive multi-order self-modelling network model that conceptualizes and approximates transformative organizational cultural change. The implemented mechanisms of organizational processes were based on an extensive literature study and grounded in related work in this field (Canbaloğlu et al., 2021), creating the described computational model of this study.

6.1. Evaluation of the computational model for the research focus

To confirm the validity of the created computational model, a scenario and variations to it were created, enabling us to compare the models' emergent behaviours. To further substantiate the model, the results of the variations of the scenario got compared to the base scenario, to gain knowledge about possible network effects (is there a better way to say something like "observe interplays and isolations of the mechanisms" again).

Table 6
Base connectivity for the second-order self-model states.

mb	base connectivity	1	2	3	4	5
X_{55}	$\mathbf{H}_{Young1}$	X_{54}	X_{67}	X_{75}		
X_{56}	$\mathbf{H}_{Young2\text{-}3\text{-}4}$	X_{67}	X_{75}			
X_{57}	$\mathbf{H}_{Expert}$	X_{54}	X_{67}			
X_{58}	$\mathbf{H}_{Team}$	X_{72}	X_{67}			
X_{59}	$\mathbf{H}_{Org}$	X_{64}				
X_{60}	context_transformational_hiding_error_workshop	X_{60}				
X_{61}	control_workshop_trigger	X_{60}	X_{52}	X_{53}		
X_{62}	$\mathbf{WW}_{error\_occurs,\ error\_proactive}$	X_{61}				
X_{63}	$\mathbf{WW}_{E,\ Y1}$	X_{54}				
X_{64}	context_transformational_monhtly_meeting_sharing	X_{64}				
X_{65}	$\mathbf{WW}_{Feedforward}$	X_{64}				
X_{66}	$\mathbf{WW}_{E\_Feedforward}$	X_{64}				
X_{67}	context_transformational_monhtly_meeting_discussion	X_{67}				
X_{68}	$\mathbf{WW}_{Feedback}$	X_{67}				
X_{69}	control_change_of_teams	X_{69}				
X_{70}	$\mathbf{T}_{YoungT1T3}$	X_{69}	X_{71}			
X_{71}	maintain_threshold	X_{71}				
X_{72}	context_transformational_daily_meeting_sharing	X_{77}	X_{78}	X_{79}		
X_{73}	$\mathbf{WW}_{team\_Feedforward}$	X_{72}				
X_{74}	$\mathbf{WW}_{team\_E\_Feedforward}$	X_{72}				
X_{75}	context_transformational_daily_meeting_discussion	X_{80}	X_{81}	X_{82}		
X_{76}	$\mathbf{WW}_{team\_feedback}$	X_{75}	X_{67}			
X_{77}	day_one_sharing	X_{77}				
X_{78}	day_two_sharing	X_{78}				
X_{79}	day_three_sharing	X_{79}				
X_{80}	day_one_discussion	X_{80}				
X_{81}	day_two_discussion	X_{81}				
X_{82}	day_three_discussion	X_{82}				

Table 7
Connection weights for the base level states.

mcw	connection weights	1	2	3	4	5
X_1	Y1T1	1				
X_2	Y1T2	X_{28}				
X_3	Y1T3	X_{29}	X_{30}			
X_4	Y2T1	1				
X_5	Y2T2	X_{31}				
X_6	Y2T3	X_{32}	X_{33}			
X_7	Y3T1	1				
X_8	Y3T2	X_{34}				
X_9	Y3T3	X_{35}	X_{36}			
X_{10}	Y4T1	1				
X_{11}	Y4T2	X_{37}				
X_{12}	Y4T3	X_{38}	X_{39}			
X_{13}	Team1T1	1				
X_{14}	Team1T2	X_{40}				
X_{15}	Team1T3	X_{41}	X_{42}			
X_{16}	Team2T1	1				
X_{17}	Team2T2	X_{43}				
X_{18}	Team2T3	X_{44}	X_{45}			
X_{19}	ET1	1				
X_{20}	ET2	X_{46}				
X_{21}	ET3	X_{47}	X_{48}			
X_{22}	OrgT1	1				
X_{23}	OrgT2	X_{49}				
X_{24}	OrgT3	X_{50}	X_{51}			
X_{25}	WST1	1				
X_{26}	WST2	1	1			
X_{27}	WST3	1	1			

Table 8
Connection weights for the first-order self-model states.

mcw	connection weights	1	2	3	4	5
X_{28}	$\mathbf{W}_{Y1T1,Y1T2}$	X_{76}	X_{63}	1		
X_{29}	$\mathbf{W}_{Y1T2,Y1T3}$	X_{76}	X_{63}	1		
X_{30}	$\mathbf{W}_{Y1T1,Y1T3}$	X_{76}	X_{63}	1		
X_{31}	$\mathbf{W}_{Y2T1,Y1T2}$	X_{76}	1			
X_{32}	$\mathbf{W}_{Y2T2,Y1T3}$	X_{76}	1			
X_{33}	$\mathbf{W}_{Y2T1,Y1T3}$	X_{76}	1			
X_{34}	$\mathbf{W}_{Y3T1,Y3T2}$	X_{76}	1			
X_{35}	$\mathbf{W}_{Y3T2,Y3T3}$	X_{76}	1			
X_{36}	$\mathbf{W}_{Y3T1,Y3T3}$	X_{76}	1			
X_{37}	$\mathbf{W}_{Y4T1,Y4T2}$	X_{76}	1			
X_{38}	$\mathbf{W}_{Y4T2,Y4T3}$	X_{76}	1			
X_{39}	$\mathbf{W}_{Y4T1,Y4T3}$	X_{76}	1			
X_{40}	$\mathbf{W}_{Team1T1,\ Team1T2}$	X_{68}	X_{73}	X_{73}	0.5	X_{74}
X_{41}	$\mathbf{W}_{Team1T2,\ Team1T3}$	X_{68}	X_{73}	X_{73}	0.5	X_{74}
X_{42}	$\mathbf{W}_{Team1T1,\ Team1T3}$	X_{68}	X_{73}	X_{73}	0.5	X_{74}
X_{43}	$\mathbf{W}_{Team2T1,\ Team2T2}$	X_{68}	X_{73}	X_{73}	0.5	X_{74}
X_{44}	$\mathbf{W}_{Team2T2,\ Team2T3}$	X_{68}	X_{73}	X_{73}	0.5	X_{74}
X_{45}	$\mathbf{W}_{Team2T1,\ Team2T3}$	X_{68}	X_{73}	X_{73}	0.5	X_{74}
X_{46}	$\mathbf{W}_{ET1,\ ET2}$	X_{68}	1			
X_{47}	$\mathbf{W}_{ET2,\ ET3}$	X_{68}	1			
X_{48}	$\mathbf{W}_{ET1,\ ET3}$	X_{68}	1			
X_{49}	$\mathbf{W}_{OrgT1,\ OrgT2}$	X_{65}	X_{65}	X_{66}	1	
X_{50}	$\mathbf{W}_{OrgT2,\ OrgT3}$	X_{65}	X_{65}	X_{66}	1	
X_{51}	$\mathbf{W}_{OrgT1,\ OrgT3}$	X_{65}	X_{65}	X_{66}	1	
X_{52}	error_occurs	−1	1			
X_{53}	error_proactive	X_{62}				
X_{54}	supervisor_reflection	1				

Overall, the simulations are in line with the academic findings and show expected emergent behaviour. The variations of the base simulation further enabled us to observe interplays and isolations of the mechanisms. As previously established the study and model took specific research focus on certain theories, which were considered of importance to be explored within the limitations of this research.

We observed and confirmed for the model that learning from mistakes is a powerful tool for individual learning (Kucharska & Bedford, 2020) and that leadership instructed (Łukasik, 2018) change in organizational structures (restructuring/shuffling teams) resulted in an increased focus on work, significantly influencing individuals' ability to adapt their mental models. We could further confirm that organizational culture change incentives (Johnson et al., 2016; Wijethilake et al., 2021), were effective in changing the personal mistake handling of individuals. Overall the model as well demonstrates a cultural shift towards a constant learning culture, verifiable by many and interacting learning opportunities occurring.

Additionally, we recognized that successful organizational learning

Table 9
Connection weights for the second-order self-model states.

mcw	connection weights	1	2	3	4	5
X_{55}	$\mathbf{H}_{Young1}$	1	1	0.2		
X_{56}	$\mathbf{H}_{Young2\text{-}3\text{-}4}$	1	0.2			
X_{57}	$\mathbf{H}_{Expert}$	1	1			
X_{58}	$\mathbf{H}_{Team}$	1	1			
X_{59}	$\mathbf{H}_{Org}$	1				
X_{60}	context_transformational_hiding_error_workshop	1				
X_{61}	control_workshop_trigger	−1	1	−1		
X_{62}	$\mathbf{WW}_{error\_occurs,\ error\_proactive}$	1				
X_{63}	$\mathbf{WW}_{E,\ Y1}$	1				
X_{64}	context_transformational_monhtly_meeting_sharing	1				
X_{65}	$\mathbf{WW}_{Feedforward}$	0.6				
X_{66}	$\mathbf{WW}_{E\_Feedforward}$	1				
X_{67}	context_transformational_monhtly_meeting_discussion	1				
X_{68}	$\mathbf{WW}_{Feedback}$	1				
X_{69}	control_change_of_teams	1				
X_{70}	$\mathbf{T}_{YoungT1T3}$	0.4	1			
X_{71}	maintain_threshold	1				
X_{72}	context_transformational_daily_meeting_sharing	1	1	1		
X_{73}	$\mathbf{WW}_{team\_Feedforward}$	0.15				
X_{74}	$\mathbf{WW}_{team\_E\_Feedforward}$	0.15				
X_{75}	context_transformational_daily_meeting_discussion	1	1	1		
X_{76}	$\mathbf{WW}_{team\_feedback}$	1	1			
X_{77}	day_one_sharing	1				
X_{78}	day_two_sharing	1				
X_{79}	day_three_sharing	1				
X_{80}	day_one_discussion	1				
X_{81}	day_two_discussion	1				
X_{82}	day_three_discussion	1				

Table 10
Combination function weights for the base level states.

mcfw	combination function weights	1 id	2 alogistic	3 steponce
X_1	Y1T1	1		
X_2	Y1T2	1		
X_3	Y1T3		1	
X_4	Y2T1	1		
X_5	Y2T2	1		
X_6	Y2T3		1	
X_7	Y3T1	1		
X_8	Y3T2	1		
X_9	Y3T3		1	
X_{10}	Y4T1	1		
X_{11}	Y4T2	1		
X_{12}	Y4T3		1	
X_{13}	Team1T1	1		
X_{14}	Team1T2	1		
X_{15}	Team1T3		1	
X_{16}	Team2T1	1		
X_{17}	Team2T2	1		
X_{18}	Team2T3		1	
X_{19}	ET1	1		
X_{20}	ET2	1		
X_{21}	ET3		1	
X_{22}	OrgT1	1		
X_{23}	OrgT2	1		
X_{24}	OrgT3		1	
X_{25}	WST1	1		
X_{26}	WST2		1	
X_{27}	WST3		1	

Table 11
Combination function weights for the first-order self-model states.

mcfw	combination function weights	1 id	2 alogistic	3 steponce
X_{28}	$\mathbf{W}_{Y1T1,Y1T2}$		1	
X_{29}	$\mathbf{W}_{Y1T2,Y1T3}$		1	
X_{30}	$\mathbf{W}_{Y1T1,Y1T3}$		1	
X_{31}	$\mathbf{W}_{Y2T1,Y1T2}$		1	
X_{32}	$\mathbf{W}_{Y2T2,Y1T3}$		1	
X_{33}	$\mathbf{W}_{Y2T1,Y1T3}$		1	
X_{34}	$\mathbf{W}_{Y3T1,Y3T2}$		1	
X_{35}	$\mathbf{W}_{Y3T2,Y3T3}$		1	
X_{36}	$\mathbf{W}_{Y3T1,Y3T3}$		1	
X_{37}	$\mathbf{W}_{Y4T1,Y4T2}$		1	
X_{38}	$\mathbf{W}_{Y4T2,Y4T3}$		1	
X_{39}	$\mathbf{W}_{Y4T1,Y4T3}$		1	
X_{40}	$\mathbf{W}_{Team1T1,\ Team1T2}$		1	
X_{41}	$\mathbf{W}_{Team1T2,\ Team1T3}$		1	
X_{42}	$\mathbf{W}_{Team1T1,\ Team1T3}$		1	
X_{43}	$\mathbf{W}_{Team2T1,\ Team2T2}$		1	
X_{44}	$\mathbf{W}_{Team2T2,\ Team2T3}$		1	
X_{45}	$\mathbf{W}_{Team2T1,\ Team2T3}$		1	
X_{46}	$\mathbf{W}_{ET1,\ ET2}$		1	
X_{47}	$\mathbf{W}_{ET2,\ ET3}$		1	
X_{48}	$\mathbf{W}_{ET1,\ ET3}$		1	
X_{49}	$\mathbf{W}_{OrgT1,\ OrgT2}$		1	
X_{50}	$\mathbf{W}_{OrgT2,\ OrgT3}$		1	
X_{51}	$\mathbf{W}_{OrgT1,\ OrgT3}$		1	
X_{52}	error_occurs		1	
X_{53}	error_proactive	1		
X_{54}	supervisor_reflection	1		

via feed-forward and feedback learning as described by (Crossan et al. (1999), can (at least in some contexts) necessitate a monthly meeting with full organizational sharing, reflection and learning, to allow for a significant correction of the mental model (Canbaloğlu, et al., 2023a), suggesting the occurrence of unexplored network effects within the model. Further, the simulations show that the daily shift reflections have a constant and robust positive impact on the correction of the mental models, suggesting this tool as the most reliable mechanism to choose.

Lastly, the model and its results further confirm that the self-modelling approach by Treur (2020) is a suitable approach to formalize the systems model of organizational change (Maes & Van Hootegem, 2019) and the proposed dynamic systems view of organizations (Farla et al., 2012; Hazy & Silberstang, 2009). In addition, this has validated previous more theoretical research (Treur, 2021b) showing by mathematical analysis that any adaptive dynamical system can be modelled as a self-modelling network.

Table 12
Combination function weights for the second-order self-model states.

mcfw	combination function weights	1 id	2 alogistic	3 steponce
X_{55}	$\mathbf{H}_{\text{Young1}}$		1	
X_{56}	$\mathbf{H}_{\text{Young2-3-4}}$		1	
X_{57}	$\mathbf{H}_{\text{Expert}}$		1	
X_{58}	$\mathbf{H}_{\text{Team}}$		1	
X_{59}	$\mathbf{H}_{\text{Org}}$		1	
X_{60}	context_transformational_hiding_error_workshop			1
X_{61}	control_workshop_trigger		1	
X_{62}	$\mathbf{WW}_{\text{error\_occurs, error\_proactive}}$	1		
X_{63}	$\mathbf{WW}_{\text{E, Y1}}$		1	
X_{64}	context_transformational_monhtly_meeting_sharing			1
X_{65}	$\mathbf{WW}_{\text{Feedforward}}$	1		
X_{66}	$\mathbf{WW}_{\text{E\_Feedforward}}$	1		
X_{67}	context_transformational_monhtly_meeting_discussion			1
X_{68}	$\mathbf{WW}_{\text{Feedback}}$	1		
X_{69}	control_change_of_teams			1
X_{70}	$\mathbf{T}_{\text{YoungT1T3}}$		1	
X_{71}	maintain_threshold	1		
X_{72}	context_transformational_daily_meeting_sharing		1	
X_{73}	$\mathbf{WW}_{\text{team\_Feedforward}}$	1		
X_{74}	$\mathbf{WW}_{\text{team\_E\_Feedforward}}$	1		
X_{75}	context_transformational_daily_meeting_discussion		1	
X_{76}	$\mathbf{WW}_{\text{team\_feedback}}$		1	
X_{77}	day_one_sharing			1
X_{78}	day_two_sharing			1
X_{79}	day_three_sharing			1
X_{80}	day_one_discussion			1
X_{81}	day_two_discussion			1
X_{82}	day_three_discussion			1

Table 13
Combination function parameters for the base level states.

mcfp	combination function parameters	1 id	2 alogistic σ	τ	3 steponce α	β
X_1	Y1T1					
X_2	Y1T2					
X_3	Y1T3		5	0.3		
X_4	Y2T1					
X_5	Y2T2					
X_6	Y2T3		5	0.3		
X_7	Y3T1					
X_8	Y3T2					
X_9	Y3T3		5	0.3		
X_{10}	Y4T1					
X_{11}	Y4T2					
X_{12}	Y4T3		5	0.3		
X_{13}	Team1T1					
X_{14}	Team1T2					
X_{15}	Team1T3		5	0.3		
X_{16}	Team2T1					
X_{17}	Team2T2					
X_{18}	Team2T3		5	0.3		
X_{19}	ET1					
X_{20}	ET2					
X_{21}	ET3		5	0.3		
X_{22}	OrgT1					
X_{23}	OrgT2					
X_{24}	OrgT3		5	0.3		
X_{25}	WST1					
X_{26}	WST2		5	1		
X_{27}	WST3		5	1		

Table 14
Combination function parameters for the first-order self-model states.

mcfp	combination function parameters	1 id	2 alogistic σ	τ	3 steponce β
X_{28}	$\mathbf{W}_{\text{Y1T1,Y1T2}}$		5	0.5	
X_{29}	$\mathbf{W}_{\text{Y1T2,Y1T3}}$		5	0.5	
X_{30}	$\mathbf{W}_{\text{Y1T1,Y1T3}}$		5	X_{70}	
X_{31}	$\mathbf{W}_{\text{Y2T1,Y1T2}}$		5	0.5	
X_{32}	$\mathbf{W}_{\text{Y2T2,Y1T3}}$		5	0.5	
X_{33}	$\mathbf{W}_{\text{Y2T1,Y1T3}}$		5	X_{70}	
X_{34}	$\mathbf{W}_{\text{Y3T1,Y3T2}}$		5	0.5	
X_{35}	$\mathbf{W}_{\text{Y3T2,Y3T3}}$		5	0.5	
X_{36}	$\mathbf{W}_{\text{Y3T1,Y3T3}}$		5	X_{70}	
X_{37}	$\mathbf{W}_{\text{Y4T1,Y4T2}}$		5	0.5	
X_{38}	$\mathbf{W}_{\text{Y4T2,Y4T3}}$		5	0.5	
X_{39}	$\mathbf{W}_{\text{Y4T1,Y4T3}}$		5	X_{70}	
X_{40}	$\mathbf{W}_{\text{Team1T1, Team1T2}}$		5	0.3	
X_{41}	$\mathbf{W}_{\text{Team1T2, Team1T3}}$		5	0.3	
X_{42}	$\mathbf{W}_{\text{Team1T1, Team1T3}}$		5	0.3	
X_{43}	$\mathbf{W}_{\text{Team2T1, Team2T2}}$		5	0.3	
X_{44}	$\mathbf{W}_{\text{Team2T2, Team2T3}}$		5	0.3	
X_{45}	$\mathbf{W}_{\text{Team2T1, Team2T3}}$		5	0.3	
X_{46}	$\mathbf{W}_{\text{ET1, ET2}}$		5	0.3	
X_{47}	$\mathbf{W}_{\text{ET2, ET3}}$		5	0.3	
X_{48}	$\mathbf{W}_{\text{ET1, ET3}}$		5	0.9	
X_{49}	$\mathbf{W}_{\text{OrgT1, OrgT2}}$		5	0.3	
X_{50}	$\mathbf{W}_{\text{OrgT2, OrgT3}}$		5	0.3	
X_{51}	$\mathbf{W}_{\text{OrgT1, OrgT3}}$		5	0.3	
X_{52}	error_occurs		5	0.2	
X_{53}	error_proactive				
X_{54}	supervisor_reflection				

6.2. *Practical implications*

This study's results and observations suggest a few different practical implications concerning transformative organizational change initiatives. The simulations clearly show that a combined approach of all mechanisms is the most effective option given arising interplay and network effects, suggesting that real-world initiatives should as well employ numerous mechanisms at the same time. Further, it seems that daily reflections are the most powerful organizational learning tool in correcting wrong knowledge offering a reason for managers to prioritize this instrument. However, it should be noted that learning from mistakes enabled better and more effective learning during the daily reflections, suggesting their use in tandem. Lastly, the simulations delivered strong results concerning the effect of increased organizational learning by

Table 15
Combination function parameters for the second-order self-model states.

mcfp	combination function parameters	1 id	2 alogistic σ	 τ	3 steponce α	 β
X_{55}	$\mathbf{H}_{\text{Young1}}$		50	0.2		
X_{56}	$\mathbf{H}_{\text{Young2-3-4}}$		50	0.2		
X_{57}	$\mathbf{H}_{\text{Expert}}$		50	0.2		
X_{58}	$\mathbf{H}_{\text{Team}}$		50	0.2		
X_{59}	$\mathbf{H}_{\text{Org}}$		50	0.2		
X_{60}	context_transformational_hiding_error_workshop				0	10
X_{61}	control_workshop_trigger		5	0.2		
X_{62}	$\mathbf{WW}_{\text{error\_occurs, error\_proactive}}$					
X_{63}	$\mathbf{WW}_{\text{E, Y1}}$		50	0.1		
X_{64}	context_transformational_monhtly_meeting_sharing				150	151
X_{65}	$\mathbf{WW}_{\text{Feedforward}}$					
X_{66}	$\mathbf{WW}_{\text{E\_Feedforward}}$					
X_{67}	context_transformational_monhtly_meeting_discussion				170	171
X_{68}	$\mathbf{WW}_{\text{Feedback}}$					
X_{69}	control_change_of_teams				130	200
X_{70}	$\mathbf{T}_{\text{YoungT1T3}}$		5	0.3		
X_{71}	maintain_threshold					
X_{72}	context_transformational_daily_meeting_sharing		50	0.2		
X_{73}	$\mathbf{WW}_{\text{team\_Feedforward}}$					
X_{74}	$\mathbf{WW}_{\text{team\_E\_Feedforward}}$					
X_{75}	context_transformational_daily_meeting_discussion		50	0.2		
X_{76}	$\mathbf{WW}_{\text{team\_feedback}}$		50	0.2		
X_{77}	day_one_sharing				35	36
X_{78}	day_two_sharing				65	66
X_{79}	day_three_sharing				95	96
X_{80}	day_one_discussion				50	53
X_{81}	day_two_discussion				80	83
X_{82}	day_three_discussion				110	113

Table 16
Speed factors and initial values for the base level states.

ms iv		1 speed factors	2 initial values
X_1	Y1T1	0	1
X_2	Y1T2	1	0
X_3	Y1T3	1	0
X_4	Y2T1	0	1
X_5	Y2T2	1	0
X_6	Y2T3	1	0
X_7	Y3T1	0	1
X_8	Y3T2	1	0
X_9	Y3T3	1	0
X_{10}	Y4T1	0	1
X_{11}	Y4T2	1	0
X_{12}	Y4T3	1	0
X_{13}	Team1T1	0	1
X_{14}	Team1T2	1	0
X_{15}	Team1T3	1	0
X_{16}	Team2T1	0	1
X_{17}	Team2T2	1	0
X_{18}	Team2T3	1	0
X_{19}	ET1	0	1
X_{20}	ET2	1	0
X_{21}	ET3	1	0
X_{22}	OrgT1	0	1
X_{23}	OrgT2	1	0
X_{24}	OrgT3	1	0
X_{25}	WST1	1	0
X_{26}	WST2	1	0
X_{27}	WST3	1	0

Table 17
Speed factors and initial values for the first-order self-model states.

ms iv		1 speed factors	2 initial values
X_{28}	$\mathbf{W}_{\text{Y1T1,Y1T2}}$	X_{55}	0.1
X_{29}	$\mathbf{W}_{\text{Y1T2,Y1T3}}$	X_{55}	0.95
X_{30}	$\mathbf{W}_{\text{Y1T1,Y1T3}}$	X_{55}	0.9
X_{31}	$\mathbf{W}_{\text{Y2T1,Y1T2}}$	X_{56}	0.5
X_{32}	$\mathbf{W}_{\text{Y2T2,Y1T3}}$	X_{56}	0.95
X_{33}	$\mathbf{W}_{\text{Y2T1,Y1T3}}$	X_{56}	0.5
X_{34}	$\mathbf{W}_{\text{Y3T1,Y3T2}}$	X_{56}	0.2
X_{35}	$\mathbf{W}_{\text{Y3T2,Y3T3}}$	X_{56}	0.95
X_{36}	$\mathbf{W}_{\text{Y3T1,Y3T3}}$	X_{56}	0.8
X_{37}	$\mathbf{W}_{\text{Y4T1,Y4T2}}$	X_{56}	0.7
X_{38}	$\mathbf{W}_{\text{Y4T2,Y4T3}}$	X_{56}	0.95
X_{39}	$\mathbf{W}_{\text{Y4T1,Y4T3}}$	X_{56}	0.3
X_{40}	$\mathbf{W}_{\text{Team1T1, Team1T2}}$	X_{58}	0
X_{41}	$\mathbf{W}_{\text{Team1T2, Team1T3}}$	X_{58}	0
X_{42}	$\mathbf{W}_{\text{Team1T1, Team1T3}}$	X_{58}	0
X_{43}	$\mathbf{W}_{\text{Team2T1, Team2T2}}$	X_{58}	0
X_{44}	$\mathbf{W}_{\text{Team2T2, Team2T3}}$	X_{58}	0
X_{45}	$\mathbf{W}_{\text{Team2T1, Team2T3}}$	X_{58}	0
X_{46}	$\mathbf{W}_{\text{ET1, ET2}}$	X_{57}	1
X_{47}	$\mathbf{W}_{\text{ET2, ET3}}$	X_{57}	1
X_{48}	$\mathbf{W}_{\text{ET1, ET3}}$	X_{57}	0
X_{49}	$\mathbf{W}_{\text{OrgT1, OrgT2}}$	X_{59}	0
X_{50}	$\mathbf{W}_{\text{OrgT2, OrgT3}}$	X_{59}	0
X_{51}	$\mathbf{W}_{\text{OrgT1, OrgT3}}$	X_{59}	0
X_{52}	error_occurs	1	0
X_{53}	error_proactive	1	0
X_{54}	supervisor_reflection	1	0

diverging the focus back to work implicating these as an important catalysator in organizational learning that managers should acknowledge.

6.3. Theoretical implications

This research offers a theoretical and computational expansion to the academic field of transformative organizational change by creating a functional scenario-bound model of organizational change and translating organizational processes into computational approximations.

This study, therefore, suggests an advancement of the field of transformative organizational change into the field of computational modelling and simulations. It would further be highly interesting and fitting to expand Canbaloğlu et al. (2021, 2023b) research into

Table 18
Speed factors and initial values for the second-order self-model states.

ms iv		1 speed factors	2 initial values
X_{55}	$\mathbf{H}_{Young1}$	1	0
X_{56}	$\mathbf{H}_{Young2\text{-}3\text{-}4}$	1	0
X_{57}	$\mathbf{H}_{Expert}$	1	0
X_{58}	$\mathbf{H}_{Team}$	1	0
X_{59}	$\mathbf{H}_{Org}$	1	0
X_{60}	context_transformational_hiding_error_workshop	1	0
X_{61}	control_workshop_trigger	1	0
X_{62}	$\mathbf{WW}_{error\_occurs,\ error\_proactive}$	1	0
X_{63}	$\mathbf{WW}_{E,\ Y1}$	1	0
X_{64}	context_transformational_monhtly_meeting_sharing	1	0
X_{65}	$\mathbf{WW}_{Feedforward}$	1	0
X_{66}	$\mathbf{WW}_{E\_Feedforward}$	1	0
X_{67}	context_transformational_monhtly_meeting_discussion	1	0
X_{68}	$\mathbf{WW}_{Feedback}$	1	0
X_{69}	control_change_of_teams	1	0
X_{70}	$\mathbf{T}_{YoungT1T3}$	1	0
X_{71}	maintain_threshold	1	0.5
X_{72}	context_transformational_daily_meeting_sharing	1	0
X_{73}	$\mathbf{WW}_{team\_Feedforward}$	1	0
X_{74}	$\mathbf{WW}_{team\_E\_Feedforward}$	1	0
X_{75}	context_transformational_daily_meeting_discussion	1	0
X_{76}	$\mathbf{WW}_{team\_feedback}$	1	0
X_{77}	day_one_sharing	1	0
X_{78}	day_two_sharing	1	0
X_{79}	day_three_sharing	1	0
X_{80}	day_one_discussion	1	0
X_{81}	day_two_discussion	1	0
X_{82}	day_three_discussion		0

organizational learning toward organizational transformation processes in general, in which this paper would situate itself, as a starting point for further research.

6.4. *Future research & limitations*

Nonetheless, the presented computational model and study are not without limitations. Although it reflects some transformative organizational change mechanisms and variables, many further mechanisms and with those possible hidden interactions and emergent behaviour are still missing. A further advanced model could e.g. also integrate observational learning for the task-observing doctor, or could integrate counterfactual thinking as a learning and decision mechanism as proposed in Bhalwankar and Treur (2022). While the proposed model is scenario-specific the translated mechanisms of this model can be extracted and reused in other related models. Therefore future research suggests itself in an extension of the proposed model as well as in the creation of a library of computationally translated transformative organizational change mechanisms. This would enable a rapid extension of research in the field of self-modelling and adaptive computational modelling of transformative organizational change.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix. Role Matrices

In this section, the full specification of the dynamical model is provided by the role matrices for the different types of network characteristics (see Tables 4-18).

References

Anderson, D., & Anderson, L. A. (2002). *Beyond change management: Advanced strategies for today's transformational leaders*. John Wiley & Sons.

Beech, C. E., Dowty, R. A., & Wallace, W. A. (2012). The dynamics of organisational response: simulating cultural change. *International Journal of Complexity in Leadership and Management* 14, 2(1-2), 74-103.

Bhalwankar, R., & Treur, J. (2022). 'What if I Would Have Done Otherwise…': A Controlled Adaptive Network Model for Mental Models in Counterfactual Thinking. In: Treur, J., Van Ments, L., *Mental Models and Their Dynamics, Adaptation, and Control* (pp. 117-138): Springer.

Burns, J. M. (1978). *Leadership*. New York, NY: Harper & Row.

Canbaloğlu, G., Treur, J., & Roelofsma, P. H. M. P. (2021). Computational modeling of organisational learning by self-modeling networks. *Cognitive Systems Research, 73*, 51–64.

Canbaloğlu, G., Treur, J., & Roelofsma, P.H.M.P (2023a). An Adaptive Self-Modeling Network Model for Multilevel Organisational Learning. In *Proceedings of the 7th International Congress on Information and Communication Technology, ICICT'22. Lecture Notes in Networks and Systems*, vol 448, pp. 179-191. Springer Nature Switzerland AG.

Canbaloğlu, G., Treur, J., & Wiewiora, A. (2022). Computational Modeling of Multilevel Organisational Learning: From Conceptual to Computational Mechanisms. *Proceedings of Computational Intelligence: Automate Your World, InCITe'22. Lecture Notes in Electrical Engineering*, vol. 968. Springer Nature, Cham.

Canbaloğlu, G., Treur, J., & Wiewiora (Eds.), A. (2023b). *Computational Modeling of Multilevel Organisational Learning and its Control Using Self-Modeling Network Models*. Springer Nature, Cham.

Clark, G. (2002). Organisational culture and safety: An interdependent relationship. *Australian Health Review, 25*(6), 181–189.

Cresswell, J. (2007). *Qualitative inquiry and research design*, 2 nd edn, Thousand Oak. In: CA, Sage.

Crossan, M. M., Lane, H. W., & White, R. E. (1999). An organizational learning framework: From intuition to institution. *Academy of management review, 24*(3), 522–537.

Edmondson, A. C., & McManus, S. E. (2007). Methodological fit in management field research. *Academy of management review, 32*(4), 1246–1264.

Farla, J., Markard, J., Raven, R., & Coenen, L. (2012). Sustainability transitions in the making: A closer look at actors, strategies and resources. *Technological forecasting and social change, 79*(6), 991–998.

Haack, P., Martignoni, D., & Schoeneborn, D. (2021). A bait-and-switch model of corporate social responsibility. *Academy of management review, 46*(3), 440–464.

Halligan, M., & Zecevic, A. (2011). Safety culture in healthcare: A review of concepts, dimensions, measures and progress. *BMJ quality & safety, 20*(4), 338–343.

Hazy, J. K., & Silberstang, J. (2009). Leadership within emergent events in complex systems: Micro-enactments and the mechanisms of organisational learning and change. *International Journal of learning and Change, 3*(3), 230–247.

Hornstein, H. A. (2015). The integration of project management and organizational change management is now a necessity. *International journal of project management, 33*(2), 291–298.

Johnson, A., Nguyen, H., Groth, M., Wang, K., & Ng, J. L. (2016). Time to change: A review of organisational culture change in health care organisations. *Journal of Organizational Effectiveness: People and Performance.*

Kucharska, W. (2021). Do mistakes acceptance foster innovation? Polish and US cross-country study of tacit knowledge sharing in IT. *Journal of Knowledge Management.*

Kucharska, W., & Bedford, D. A. (2020). Love your mistakes!—they help you adapt to change. How do knowledge, collaboration and learning cultures foster organizational intelligence? *Journal of Organizational Change Management.*

Lewin, K. (1951). *Field Theory in Social Science'*. New York: Harper and Row.

Limwichitr, S., Broady-Preston, J., & Ellis, D. (2015). A discussion of problems in implementing organisational cultural change: Developing a learning organisation in university libraries. *Library Review.*

Łukasik, K. (2018). Mechanisms of changes of organisational culture in corporate environment. Organizacja i Zarządzanie: kwartalnik naukowy.

Maes, G., & Van Hootegem, G. (2019). A systems model of organizational change. *Journal of Organizational Change Management*.

Mangels, J. A., Butterfield, B., Lamb, J., Good, C., & Dweck, C. S. (2006). Why do beliefs about intelligence influence learning success? A social cognitive neuroscience model. *Social cognitive and affective neuroscience, 1*(2), 75–86.

Markard, J., Raven, R., & Truffer, B. (2012). Sustainability transitions: An emerging field of research and its prospects. *Research policy, 41*(6), 955–967.

Mascarenhas, S. O. A. (2019). The Ethics of Corporate Critical Thinking. In *Corporate Ethics for Turbulent Markets*. Emerald Publishing Limited.

Mohsin, S. U., Ibrahim, Y., & Levine, D. (2019). Teaching medical students to recognise and report errors. *BMJ Open Quality, 8*(2), e000558.

Ojogiwa, O. T., & Qwabe, B. R. (2021). Leveraging on the Management of Organisational Cultural Change for an Improved Change Outcome in the Nigerian Public Health Sector. *African Journal of Governance & Development, 10*(1), 61–79.

Rass, L., Treur, J., Kucharska, W., Wiewiora, A.: Computational Modelling of Transformational Organizational Change in the Context of Organisational Culture & Learning: From Theory towards a Computational Model with an Application in Hospital-related Safety Culture. Proc. BICA*AI'22 CSR (2022).

Rebelo, T. M., & Gomes, A. D. (2011). Conditioning factors of an organizational learning culture. *Journal of Workplace Learning*.

Sandberg, J., & Alvesson, M. (2011). Ways of constructing research questions: Gap-spotting or problematization? *Organization, 18*(1), 23–44.
Schein, E. H. (2010). *Organizational culture and leadership, (Vol. 2):*. John Wiley & Sons.
Senge, P. M. (2006). The fifth discipline: The art and practice of the learning organization: Currency.
Sharpanskykh, A., & Stroeve, S. H. (2011). An agent-based approach for structured modeling, analysis and improvement of safety culture. *Computational and Mathematical Organization Theory, 17*(1), 77–117.
Tranfield, D., Denyer, D., & Smart, P. (2003). Towards a methodology for developing evidence-informed management knowledge by means of systematic review. *British journal of management, 14*(3), 207–222.
Treur, J. (2016). Dynamic modeling based on a temporal–causal network modeling approach. *Biologically Inspired Cognitive Architectures, 16*, 131–168.
Treur, J. (2020). *Network-oriented modeling for adaptive networks: Designing higher-order adaptive biological, mental and social network models*. Cham: Springer Nature.
Treur, J. (2021a). Adaptive Networks at the Crossroad of Artificial Intelligence and Formal, Biological, Medical, and Social Sciences. In *Integrated Science* (pp. 335–375). Springer.
Treur, J. (2021b). On the dynamics and adaptivity of mental processes: Relating adaptive dynamical systems and self-modeling network models by mathematical analysis. *Cognitive Systems Research, 70*, 93–100.
Weick, K. E., & Quinn, R. E. (1999). Organizational change and development. *Annual review of psychology, 50*(1), 361–386.
Wiewiora, A., Chang, A., & Smidt, M. (2020). Individual, project and organizational learning flows within a global project-based organization: Exploring what, how and who. *International journal of project management, 38*(4), 201–214.
Wijethilake, C., Upadhaya, B., & Lama, T. (2021). The role of organisational culture in organisational change towards sustainability: Evidence from the garment manufacturing industry. *Production Planning & Control*, 1–20.
Willis, C. D., Saul, J., Bevan, H., Scheirer, M. A., Best, A., Greenhalgh, T., … Jenkins, E. (2016). Sustaining organizational culture change in health systems. *Journal of health organization and management.*