An Adaptive Self-Modeling Network Model for the Roles of Individual and Team Learning in Organisational Learning

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Abstract. Organisational learning is often considered to concern mental models as a vehicle for individual, team, and organizational learning. By learning individual mental models, a basis for formation of shared team mental models is created, and based on the different shared team mental models, a shared organisation mental model can be obtained. This pathway is indicated by feed forward learning. In addition, feedback learning follows the opposite pathway: shared team mental models can be learned from a shared organisation mental model and individual mental models can be learned from shared team mental models. These pathways and their interactions provide complex dynamic and adaptive mechanisms that together constitute organizational learning. These mechanisms have been used as a basis for an adaptive computational network model for organisational learning. The model is illustrated by a not too complex but realistic case study.

1. Introduction

Organizational learning is a complex, dynamic, multilevel, cyclical and non-linear type of learning both involving individuals and independent of individuals. It is multilevel because the learning of an organization involves learning at the level of individuals and at the level of teams (or groups) via feed forward and feedback pathways:

> ‘Through feed-forward processes, new ideas and actions flow from the individual to the group to the organization levels. At the same time, what has already been learned feeds back from the organization to group and individual levels, affecting how people act and think.’ (Crossan, Lane, White, 1999), p. 532.
> ‘There is growing consensus in the literature that the theory of organizational learning should consider individual, team and organizational levels’ (Wiewiora, Smidt, Chang, 2019), p. 94

There is a huge amount of literature on organizational learning such as (Argyris, Schön, 1978; Bogenrieder, 2002; Crossan et al, 1999; Fischhof, Johnson, 1997; Kim, 1993; McShane, Glinow, 2010; Stelmaszczyk, 2016; Wiewiora et al, 2019; Wiewiora, Chang, Smidt, 2020). However, systematic approaches to obtain (adaptive) computational models for it cannot be found. In the current paper, a self-modeling network modeling perspective is used to model the different adaptive, interacting processes of organizational learning.

Computational modeling of organizational learning provides a more observable formalization of organisational learning and provides possibilities to perform ‘in silico’ (simulation) experiments with it. To this end, the multi-order adaptive network-oriented modeling approach based on self-modeling networks introduced in (Treur, 2020a; Treur, 2020b) that will be explained in detail in Section 3, was used in this current paper.

First, Section 2 presents how literature provides ideas on mental models at individual, team and organisation level and their role in organizational learning. Then, Section 3 explains the characteristics and details of adaptive self-modeling network models and how they can be used to model the different processes concerning dynamics, adaptation and control of mental models. In Section 4 the second-order (controlled) adaptive network model for organisational learning via individual en team mental models is introduced. Then in Section 5, an example simulation scenario is explained in detail. Section 6 is a Discussion section.

2. Background Literature

The quotes in the introduction section illustrate the perspective adopted here. Mental models are considered a vehicle for individual learning, team learning and organizational learning. By learning individual mental models, a basis for formation of shared team mental models is provided and these shared team mental models provide input for the shared mental models at the level of the organization. Conversely, these shared organisation and team mental models are used to improve shared team mental models and individual mental models, respectively. The picture of the different pathways shown in Fig. 1 is a slightly rearranged version of Fig. 1 in (Crossan et al, 1999) and also strongly resembles Fig. 4 of (Wiewiora et al, 2019) and Fig. 3 of (Wiewiora et al, 2020).

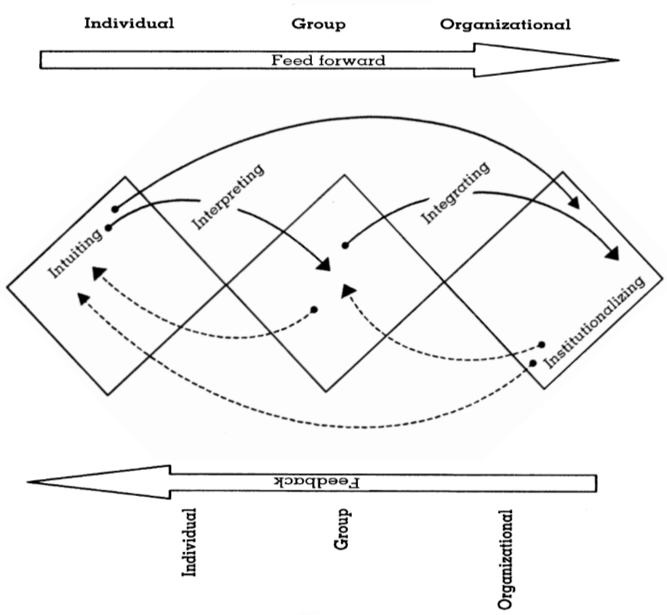

Fig. 1. Organisational learning as a dynamic process; adapted from (Crossan et al, 1999), Fig 1. For a similar picture, see (Wiewiora et al, 2019), Fig. 4 and Fig. 3 of (Wiewiora et al, 2020).

Inspired by this, as a basis for the analysis made here, the considered overall organisational learning process consists of the following main processes and interactions; see also (Crossan et al, 1999; Wiewiora et al, 2019):

(a) Individual level

(1) Creating and maintaining individual mental models
(2) Choosing for a specific context a suitable individual mental model as focus

(3) Applying a chosen individual mental model for internal simulation
(4) Improving individual mental models (individual mental model learning)

(b) From individual level to team level (feed forward learning)

(1) Deciding about creation of shared team mental models
(2) Creating shared team mental models based on developed individual mental models

(c) From team level to organization level (feed forward learning)

(1) Deciding about creation of shared mental models
(2) Creating shared mental models based on developed individual mental models

(d) From organization level to team level (feedback learning)

(1) Deciding about teams to adopt shared organisation mental models
(2) Teams adopting shared mental models

(e) From team level to individual level (feedback learning)

(1) Deciding about individuals to adopt shared team mental models
(2) Individuals adopting shared team mental models by learning them

(f) Individual level

(1) Creating and maintaining individual mental models
(2) Choosing for a specific context a suitable individual mental model as focus
(3) Applying a chosen individual mental model for internal simulation
(4) Improving individual mental models (individual mental model learning)

This overview will provide useful input to the design of the computational network model for organizational learning that will be introduced in Section 4.

3. The Self-Modeling Network Modeling Approach Used

In this section, the network-oriented modeling approach used is briefly introduced. Following (Treur, 2020b), a network model is characterised by (here X and Y denote nodes of the network, also called states):

- *Connectivity characteristics*
  Connections from a state X to a state Y and their weights $\boldsymbol{\omega}_{X,Y}$
- *Aggregation characteristics*
  For any state Y, some combination function $\mathbf{c}_Y(..)$ defines the aggregation that is applied to the impacts $\boldsymbol{\omega}_{X,Y}X(t)$ on Y from its incoming connections from states X
- *Timing characteristics*
  Each state Y has a speed factor $\boldsymbol{\eta}_Y$ defining how fast it changes for given causal impact.

The following difference (or related differential) equations that are used for simulation purposes and also for analysis of temporal-causal networks, incorporate these network characteristics $\boldsymbol{\omega}_{X,Y}$, $\mathbf{c}_Y(..)$, $\boldsymbol{\eta}_Y$ in a standard numerical format:

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

for any state Y and where X_1 to X_k are the states from which Y gets its incoming connections. Within the software environment described in (Treur, 2020b, Ch. 9), a large number of currently around 50 useful basic combination functions are included in a combination function library. The above concepts enable to design network models and their dynamics in a declarative manner, based on mathematically defined functions and relations. The examples of basic combination functions that are applied in the model introduced here can be found in Table 1.

Table 1 The combination functions used in the introduced network model

	Notation	Formula	Parameters
Advanced logistic sum	$\mathbf{alogistic}_{\sigma,\tau}(V_1, \ldots, V_k)$	$[\frac{1}{1+e^{-\sigma(V_1+\cdots+V_k-\tau)}} - \frac{1}{1+e^{\sigma\tau}}](1+e^{-\sigma\tau})$	Steepness $\sigma > 0$ Excitability threshold τ
Steponce	$\mathbf{steponce}_{\alpha,\beta}(..)$	1 if time t is between α and β, else 0	Start time α End time β
Hebbian learning	$\mathbf{hebb}_{\mu}(V_1, V_2, V_3)$	$V_1 * V_2(1 - V_3) + \mu V_3$	V_1,V_2 activation levels of the connected states; V_3 activation level of the self-model state for the connection weight. Persistence factor μ
Maximum composed with Hebbian learning	$\mathbf{max\text{-}hebb}_{\mu}(V_1, \ldots, V_k)$	$\max(\mathbf{hebb}_{\mu}(V_1, V_2, V_3), V_4, \ldots, V_k)$	V_1,V_2 activation levels of the connected states; V_3 activation level of the self-model state for the connection weight. Persistence factor μ
Scaled maximum	$\mathbf{smax}_{\lambda}(V_1, \ldots, V_k)$	$\max(V_1, \ldots, V_k)/\lambda$	Scaling factor λ

Realistic network models are usually adaptive: often not only their states but also some of their network characteristics change over time. By using a *self-modeling network* (also called a *reified* network), a similar network-oriented conceptualisation can also be applied to *adaptive* networks to obtain a declarative description using mathematically defined functions and relations for them as well; see (Treur, 2020a; Treur, 2020b). This works through the addition of new states to the network (called *self-model states*) which represent (adaptive) network characteristics. In the graphical 3D-format as shown in Section 4, such additional states are depicted at a next level (called *self-model level* or *reification level*), where the original network is at the *base level*.

As an example, the weight $\boldsymbol{\omega}_{X,Y}$ of a connection from state X to state Y can be represented (at a next self-model level) by a self-model state named $\mathbf{W}_{X,Y}$. Similarly, all other network characteristics from $\boldsymbol{\omega}_{X,Y}$, $\mathbf{c}_Y(..)$, $\boldsymbol{\eta}_Y$ can be made adaptive by including self-model states for them. For example, an adaptive speed factor $\boldsymbol{\eta}_Y$ can be represented by a self-model state named $\mathbf{H}_Y$.

As the outcome of such a process of network reification is also a network model itself, as has been shown in (Treur, 2020b, Ch 10), this self-modeling network construction can easily be applied iteratively to obtain multiple orders of self-models at multiple (first-order, second-order, …) self-model levels. For example, a second-order self-model may include a second-order self-model state $\mathbf{H}_{\mathbf{W}_{X,Y}}$ representing the speed factor $\boldsymbol{\eta}_{\mathbf{W}_{X,Y}}$ for the (learning) dynamics of first-order self-model state $\mathbf{W}_{X,Y}$ which in turn represents the adaptation of connection weight $\boldsymbol{\omega}_{X,Y}$. Similarly, a persistence factor $\boldsymbol{\mu}_{\mathbf{W}_{X,Y}}$ of such a first-order self-model state $\mathbf{W}_{X,Y}$ used for adaptation (e.g., based on Hebbian learning) can be represented by a second-order self-model state $\mathbf{M}_{\mathbf{W}_{X,Y}}$.

In the current paper, this multi-level self-modeling network perspective will be applied to obtain a second-order adaptive mental network architecture addressing the mental and social processes underlying organizational learning by proper handling of individual mental models and shared mental models. In this self-modeling network architecture the base level addresses the use of a mental model by internal simulation, the first-order self-model the adaptation of the mental model, and the second-order self-model level the control over this; see Fig. 2. In this way the three-level cognitive architecture described in (Van Ments and Treur, 2021) is formalized computationally in the form of a self-modeling network architecture.

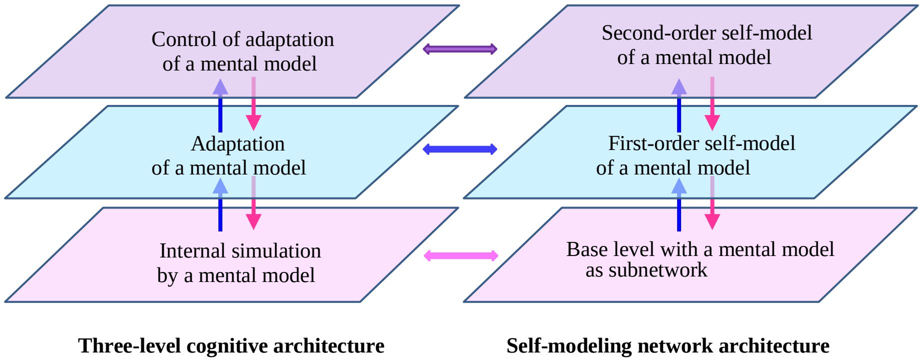

Fig. 2 Computational formalization of the three-level cognitive architecture for mental model handling from (Van Ments and Treur, 2021) by a self-modeling network architecture

In (Bhalwankar and Treur, 2021a; Bhalwankar and Treur, 2021b) it is shown how specific forms of learning and their control can be modeled based on this self-modeling network architecture, in particular observational learning (Yi and Davis, 2003; Van Gog, Paas, Marcus, Ayres, Sweller, 2009) and instructional learning (Hogan, 1997) and combinations thereof. Some of these forms of learning will also be applied in the model for organizational learning introduced here in Section 4.

4. The Adaptive Network Model for Organisational Learning

In the considered case study concerning tasks *a*, *b*, *c*, and *d*, initially the individual mental models of 4 people are different and based on some strong and some weak connections; they don't use a stronger shared mental model as that does not exist yet. The organizational learning addressed to improve the situation covers:

1. Individual (Hebbian) learning by persons of their mental models through internal simulation which results in stronger but still incomplete and different mental models. Person A and C's mental models have no connection from task *c* to task *d* and person B and D's mental models have no connection from *a* to *b*.
2. Formation of two shared team mental models for teams T1 (consisting of persons A and B) and T2 (consisting of persons C and D) based on the different individual mental models. A process of unification by aggregation takes place (feed forward learning).
3. Formation of a shared organization mental model based on the two team mental models. Again, a process of unification by aggregation takes place (feed forward learning).
4. Flow of information and knowledge from organization mental model to team mental models, e.g., a form of instructional learning (feedback learning).
5. Learning of individual mental models from the shared team mental models, e.g., also a form of instructional learning (feedback learning).
6. Improvements on these individual mental models by individual learning through internal simulation which results in stronger and now complete mental models (by Hebbian learning). Now person A and C's mental models have a connection from task c to task d, and person B and D's mental models have a connection from a to b.

The connectivity of the designed network model is depicted in Fig. 3; for an overview of the states at the base level and first-order self-modeling level, see Tables 2 and 3, and for more details about the connections and how they relate to **(a)** to **(f)** from Section 2.3, see the Appendix as Linked Data at URL https://www.researchgate.net/publication/354352746.

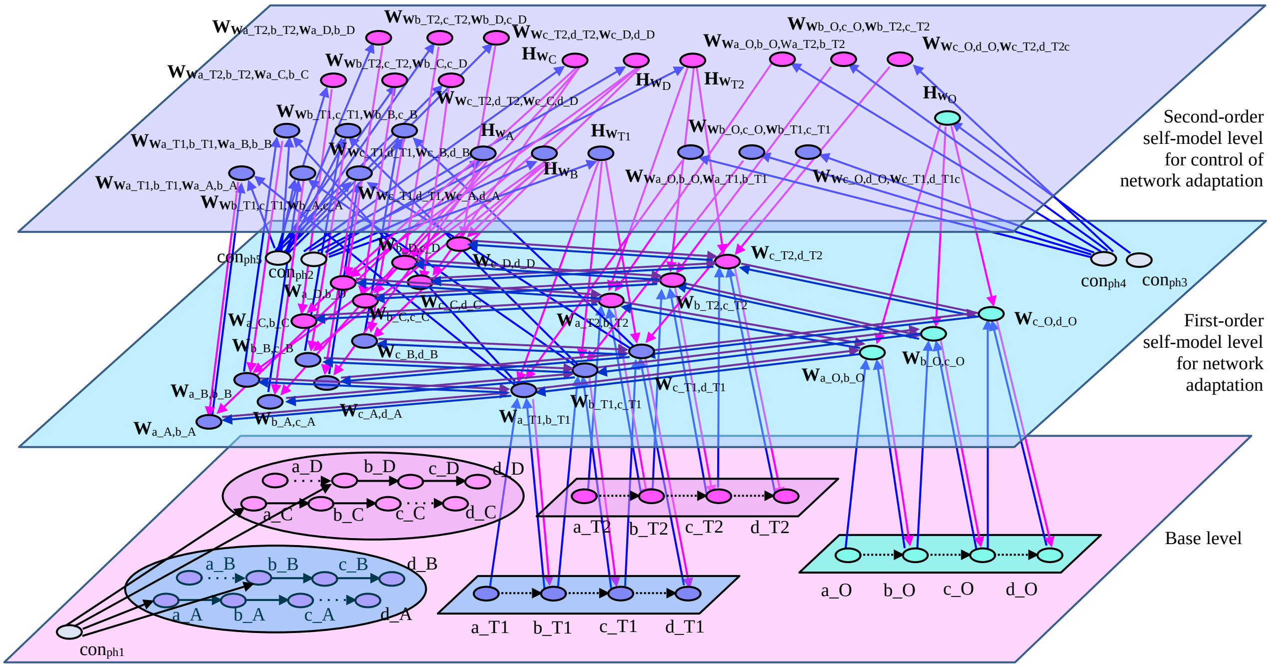

Fig. 3. The connectivity of the second-order adaptive network model for the second-order self-model of the mental models: the interactions between the first-order self-model level and the second-order self-model level: the second-order Hebbian learning for the second-order **W**-states (the $\mathbf{W}_{\mathbf{W}}$-states).

The undermost base level of this model has mental model states for individuals, teams and organization, and also context states for activation of six different phases (like the **(a)** to **(f)** in Section 2.3) at different times. The mental states of persons are connected to each other according to the order of the tasks, and the first ones has a connection from first context state to be able to start to perform internal simulation and learn.

As can be seen in Fig. 3, some connections between task states of persons are dashed, which means initially there is no connection. Therefore, states where these dashed connections are, are the 'hollow' non-known mental states of persons. These states have connections from a fifth context state to enable to observe the improvement of individual with the impact of organization and team mental models in Phase 5. The base level mental states relate to the basic tasks and can be considered as the basic ingredients of the mental models representing knowledge on relations between separate tasks.

To make the mental models adaptive, first-order self-model states are added in the intermediary level. These are **W**-states representing adaptive weights for each developed connection of individual, team and organization mental states in the base level. There are also intralevel **W**-to-**W** connections between first-order **W**-states here to provide feed forward learning in Phase 2 and Phase 3 and feedback learning in Phase 4 and Phase 5 (Crossan et al, 1999). These **W**-to-**W** connections correspond to the arrows for feed forward and feedback learning shown in Fig. 1. Formations of shared team and organization mental models are initiated by this feed forward learning mechanism, and the learning from the shared organisation mental model and the shared team mental model by individuals occurs by the feedback learning mechanism.

To control this adaptivity in first-order adaptation level, second-order self-model states are added in the uppermost level. In first place, there are $\mathbf{W}_{\mathbf{W}}$-states (higher-order **W**-states) for (intralevel) connections between first-order adaptivity level **W**-states, in other words adaptive weight representation of the connections of adaptive weight representation states in the level below. These control processes are left out of consideration in Fig. 1 based on

(Crossan et al, 1999) and (Wiewiora et al, 2019) but still are crucial for the processes to function well. Additionally, $\mathbf{H_W}$-states for adaptation speeds of connection weights in the first-order adaptation level, and $\mathbf{M_W}$-states for persistence of adaptation are placed here. This provides the speed and persistence control of the adaptation.

For a full specification of the network model by role matrices, see the Appendix as Linked Data at URL https://www.researchgate.net/publication/354352746.

Table 3 Base level states of the introduced adaptive network model

Nr	State	Explanation
X_1	a_A	Individual mental model state for person A for task a
X_2	b_A	Individual mental model state for person A for task b
X_3	c_A	Individual mental model state for person A for task c
X_4	d_A	Individual mental model state for person A for task d
X_5	a_B	Individual mental model state for person B for task a
X_6	b_B	Individual mental model state for person B for task b
X_7	c_B	Individual mental model state for person B for task c
X_8	d_B	Individual mental model state for person B for task d
X_9	a_C	Individual mental model state for person C for task a
X_{10}	b_C	Individual mental model state for person C for task b
X_{11}	c_C	Individual mental model state for person C for task c
X_{12}	d_C	Individual mental model state for person C for task d
X_{13}	a_D	Individual mental model state for person D for task a
X_{14}	b_D	Individual mental model state for person D for task b
X_{15}	c_D	Individual mental model state for person D for task c
X_{16}	d_D	Individual mental model state for person D for task d
X_{17}	a_T1	Shared mental model state for team T1 for task a
X_{18}	b_T1	Shared mental model state for team T1 for task b
X_{19}	c_T1	Shared mental model state for team T1 for task c
X_{20}	d_T1	Shared mental model state for team T1 for task d
X_{21}	a_T2	Shared mental model state for team T2 for task a
X_{22}	b_T2	Shared mental model state for team T2 for task b
X_{23}	c_T2	Shared mental model state for team T2 for task c
X_{24}	d_T2	Shared mental model state for team T2 for task d
X_{25}	a_O	Shared mental model state for organization O for task a
X_{26}	b_O	Shared mental model state for organization O for task b
X_{27}	c_O	Shared mental model state for organization O for task c
X_{28}	d_O	Shared mental model state for organization O for task d
X_{29}	con_{ph1}	Context state for Phase 1: individual mental model simulation and learning
X_{30}	con_{ph2}	Context state for Phase 2: creation of shared mental models for teams T1 and T2
X_{31}	con_{ph3}	Context state for Phase 3: creation of a shared mental model for organization O
X_{32}	con_{ph4}	Context state for Phase 4: learning shared team mental models from the shared mental model for organization O
X_{33}	con_{ph5}	Context state for Phase 5: learning individual mental models from the shared mental models for teams T1 and T2
X_{34}	con_{ph6}	Context state for Phase 6: individual mental model simulation and learning

5. Example Simulation Scenario

In this scenario, a multi-phase approach is applied to get a clear picture of the progress of organizational learning via teams. It is possible to see the feed forward flow of the development of shared team mental models from individual mental models first, formation of the shared organization mental model originating from teams' mental models then, and finally by the feedback flow the impact of these shared mental models on teams and individuals. In practice and also in the model, these phases also can overlap or take place entirely simultaneously. The considered six phases are as follows:

Table 4 First-order self-model states of the introduced adaptive network model

Nr	State	Explanation
X_{35}	$\mathbf{W}_{a\_A,b\_A}$	First-order self-model state for the weight of the connection from a to b within the individual mental model of person A
X_{36}	$\mathbf{W}_{b\_A,c\_A}$	First-order self-model state for the weight of the connection from b to c within the individual mental model of person A
X_{37}	$\mathbf{W}_{c\_A,d\_A}$	First-order self-model state for the weight of the connection from c to d within the individual mental model of person A
X_{38}	$\mathbf{W}_{a\_B,b\_B}$	First-order self-model state for the weight of the connection from a to b within the individual mental model of person B
X_{39}	$\mathbf{W}_{b\_B,c\_B}$	First-order self-model state for the weight of the connection from b to c within the individual mental model of person B
X_{40}	$\mathbf{W}_{c\_B,d\_B}$	First-order self-model state for the weight of the connection from c to d within the individual mental model of person B
X_{41}	$\mathbf{W}_{a\_C,b\_C}$	First-order self-model state for the weight of the connection from a to b within the individual mental model of person C
X_{42}	$\mathbf{W}_{b\_C,c\_C}$	First-order self-model state for the weight of the connection from b to c within the individual mental model of person C
X_{43}	$\mathbf{W}_{c\_C,d\_C}$	First-order self-model state for the weight of the connection from c to d within the individual mental model of person C
X_{44}	$\mathbf{W}_{a\_D,b\_D}$	First-order self-model state for the weight of the connection from a to b within the individual mental model of person D
X_{45}	$\mathbf{W}_{b\_D,c\_D}$	First-order self-model state for the weight of the connection from b to c within the individual mental model of person D
X_{46}	$\mathbf{W}_{c\_D,d\_D}$	First-order self-model state for the weight of the connection from c to d within the individual mental model of person D
X_{47}	$\mathbf{W}_{a\_T1,b\_T1}$	First-order self-model state for the weight of the connection from a to b within the shared mental model of team T1
X_{48}	$\mathbf{W}_{b\_T1,c\_T1}$	First-order self-model state for the weight of the connection from b to c within the shared mental model of team T1
X_{49}	$\mathbf{W}_{c\_T1,d\_T1}$	First-order self-model state for the weight of the connection from c to d within the shared mental model of team T1
X_{50}	$\mathbf{W}_{a\_T2,b\_T2}$	First-order self-model state for the weight of the connection from a to b within the shared mental model of team T2
X_{51}	$\mathbf{W}_{b\_T2,c\_T2}$	First-order self-model state for the weight of the connection from b to c within the shared mental model of team T2
X_{52}	$\mathbf{W}_{c\_T2,d\_T2}$	First-order self-model state for the weight of the connection from c to d within the shared mental model of team T2
X_{53}	$\mathbf{W}_{a\_O,b\_O}$	First-order self-model state for the weight of the connection from a to b within the shared mental model of the organisation O
X_{54}	$\mathbf{W}_{b\_O,c\_O}$	First-order self-model state for the weight of the connection from b to c within the shared mental model of the organisation O
X_{55}	$\mathbf{W}_{c\_O,d\_O}$	First-order self-model state for the weight of the connection from c to d within the shared mental model of the organisation O

- **Phase 1**: **Individual mental model usage and learning**
  This relates to **(a)** in Section 2. Different individual mental models by four different persons are constructed and strengthened here. The knowledge levels of people for the tasks, initially, are not same. Thus, the learning levels are different as can be seen in the first phase between time 25 and 200 in the simulation graph in Fig. 4 below. For example, activation levels of first three base states for tasks *a* to *c* of person A from Team 1 and person C from Team 2 (a_A to c_A and a_C to c_C) increase while the activation levels of states for task *d* (d_A and d_C) remain at zero indicating that they do not have knowledge on this task. A similar lack of knowledge is observed for the other persons B from Team 1 and D from Team 2, for task *a* this time. Therefore, the activation levels of their states a_B and a_D remain at zero in this phase, while others get increased (b_B to d_B and b_D to d_D). After this first individual learning phase, forgetting takes place for all persons because they do not have perfect persistence factors self-model **M**-state

values (values < 1, meaning imperfection). Increased **W**-states during phase 1, start to slightly decrease after phase 1 at different rates representing the differences between persons concerning forgetting speed.

- **Phase 2: Shared team mental model formation (feed forward learning)**
This relates to **(b)** in Section 2. Formation of two shared team mental models happens in this phase. The collaboration of the individuals creates the aggregation of their mental models as part of feed forward organizational learning (in this case team learning). The **W**-states of the teams ($\mathbf{W}_{a\_T1,b\_T1}$ to $\mathbf{W}_{c\_T1,d\_T1}$ and $\mathbf{W}_{a\_T2,b\_T2}$ to $\mathbf{W}_{c\_T2,d\_T2}$) increase at different rates in Phase 2 between time 250 and 300 in Fig. 4. Team 1 becomes better at the connection $c \rightarrow d$, and Team 2 becomes better at connection $a \rightarrow b$ because the teams have different persons. Then, these shared mental models are maintained by the two teams.
- **Phase 3: Shared organization mental model formation (feed forward learning)**
This relates to **(c)** in Section 2. A shared organization mental model is formed in this phase from the unification and aggregation of the two shared team mental models. The values of shared organization mental model **W**-states ($\mathbf{W}_{a\_O,b\_O}$ to $\mathbf{W}_{c\_O,d\_O}$) increase here between time 350 and 400.

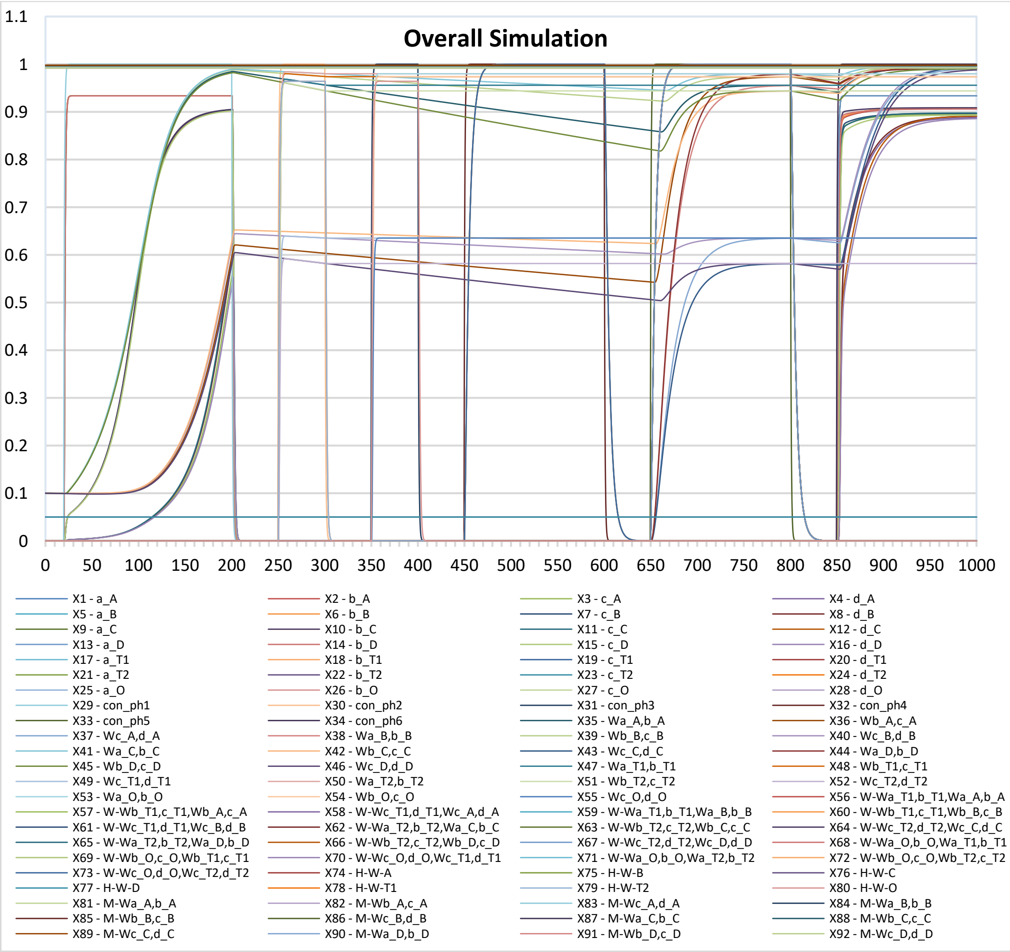

Fig. 4. Simulation graph showing all states

- **Phase 4: Feedback learning of the shared team mental model from the shared organization mental model** This relates to **(d)** in Section 2. Knowledge from the shared organization mental model is received by the team mental models as a form of (instructional) feedback learning here in this phase. The (higher-order adaptive) connections from organization **W**-states to teams **W**-states (X_{68} to X_{73}) become activated, and the teams start to get stronger connections about tasks.
- **Phase 5: Feedback learning of the individual mental models from the shared team mental models** This relates to **(e)** in Section 2. Improved knowledge from shared team mental models is received by individuals as a form of (instructional) feedback learning in this phase. Higher-order adaptive weight states for connections from teams **W**-states to individual **W**-states (X_{56} to X_{67}) are activated. This provides the learning of individual mental models and gives persons the chance of improving their unknown connections in the next phase. For instance, the person A starts to learn about the task *d* that it does not know in the beginning by the help of its team. In Fig. 4, the **W**-states of persons make jumps in this Phase 5 between time 650 and 800.
- **Phase 6: Individual mental model usage and learning**
  This relates to **(f)** in Section 2. Persons start to further improve their knowledge and skills (their mental models) already strengthened in Phase 5 by Hebbian learning. Person A's knowledge on task *d* (state d_A) becomes nonzero now (obtained via shared team mental model) and similar improvements are observed for other persons and their 'hollow' unknown states.

6. Discussion

Within mainstream organisational learning literature such as (Crossan et al, 1999; Wiewiora et al., 2019), mental models at individual, team and organisation levels are considered to be a vehicle for organizational learning. Based on developed individual mental models, by socalled feed forward learning the formation of shared team mental models can take place and based on them, a shared mental model for the level of the organization as a whole (see also Fig. 1 adopted from the mentioned literature). Once these shared mental models have been formed, they can be adopted by individuals within the organization, indicated as feedback learning. This involves a number of mechanisms of different types that by their cyclical interaction together can be considered to form the basis of organizational learning. These mechanisms have been formalized in a computational manner here and brought together in an adaptive self-modeling network architecture. The model was illustrated by a relatively simple but realistic case study. For the sake of presentation, in the case study scenario the different types of mechanisms have been controlled in such a manner that they are sequentially over time. This is not inherent in the designed computational network model: these processes can equally well work simultaneously. The two lowest levels of the three-level network model describe Fig. 1 very well, especially the intralevel connections within the middle level directly correspond to the arrows in Fig. 1. However, the necessary control of these processes is left out of consideration in Fig. 1, but is fully addressed here by the highest (third) level.

One of the extension possibilities concerns the type of aggregation used for the process of shared mental model formation. In the current model this has been based on the maximal knowledge about a specific mental model connection. But other forms of aggregation can equally well be applied, for example weighted averages. Another possible extension is to make states used for the control adaptive in a more context-sensitive manner, such as the second-order self-model **H**- and **M**-states for the individuals, which for the sake of simplicity were kept constant in the current example scenario.

References

1. Argyris Ch., Schön D.A. (1978): Organizational Learning: A Theory of Action Perspective. Addison-Wesley, Reading, MA.
2. Bogenrieder, I. (2002) Social architecture as a prerequisite for organizational learning, Management Learning, vol 33, no. 2, pp. 197-216
3. Bhalwankar, R., Treur, J. (2021a). A Second-Order Adaptive Network Model for Learner-Controlled Mental Model Learning Processes. In: Benito R.M., Cherifi C., Cherifi H., Moro E., Rocha L.M., Sales-Pardo M. (eds), Proc. of the 9th International Conference on Complex Networks and their Applications. Studies in Computational Intelligence, vol 944, pp. 245-259. Springer Nature Switzerland AG (2021b).
4. Bhalwankar, R., Treur, J. (2021b). Modeling Learner-Controlled Mental Model Learning Processes by a Second-Order Adaptive Network Model. PLoS One (2021b).
5. Burthscher, M.J., Kolbe, M., Wacker, J.: Interaction of team mental models and monitoring behaviors predict team performance in simulated anesthesia inductions. Journal of Experimental Psychology: Applied 17(3), 257-269 (2011).
6. Canbaloğlu, G., Treur, J.: Modeling Context-Sensitive Metacognitive Control of Focusing on a Mental Model During a Mental Process. Proc. of the 5th International Conference on Computational Methods in Systems and Software, CoMeSySo'21. Lecture Notes in Networks and Systems, Springer Nature.
7. Craik, K.J.W.: The nature of explanation. Cambridge, MA: University Press (1943).
8. Crossan, M.M., Lane, H.W., White, R.E. (1999). An organizational learning framework: From intuition to institution. Academy of Management Review 24, 522–537 (1999).
9. DeChurch, L.A., Mesmer-Magnus, J.R.: Measuring shared team mental models. A meta-analysis. In Group Dynamics: Theory, Research, and Practice 14(1), 1–14 (2010).
10. Dionne, S.D., Sayama, H., Hao, C., Bush, B.J.. The role of leadership in shared mental model convergence and team performance improvement: An agent-based computational model. The Leadership Quarterly 21, 1035–1049 (2010).
11. Fischhof, B., Johnson, S.: Organisational Decision Making. Cambridge: Cambridge University Press (1997).
12. Hebb, D.O.: The organization of behavior: A neuropsychological theory. New York: John Wiley and Sons (1949).
13. Higgs, A., McGrath, B.A., Goddard, C., Rangasami, J., Suntharalingam, G., Gale, R., Cook, T.M.: Guidelines for the management of tracheal intubation of critically ill adults. British Journal of Anaesthesia 120(2), 323-352 (2018).
14. Kim, D.H. (1993). The Link Between Individual and Organisational Learning. Sloan Management Review, Fall 1993, pp. 37-50. Also in: Klein, D.A. (ed.), The Strategic Management of Intellectual Capital. Routledge-Butterworth-Heinemann, Oxford. (Cited by 4688 in Google Scholar dd. August 10, 2021)
15. Langan-Fox, J., Code, S., Langfield-Smith, K.: Team mental models. Techniques, methods, and analytic approaches. Human factors 42(2), 242–271 (2000).
16. McShane, S.L., Glinow, M.A. von (2010). Organizational Behavior. McGraw-Hill, Boston..
17. Mathieu, J.E., Hefner, T.S., Goodwin, G.F., Salas, E., Cannon-Bowers, J.A.: The influence of shared mental models on team process and performance. J. of Applied Psychology 85(2), 273-283 (2000).
18. Nini, M.: All on the same page: How Team Mental Models (TMM) increase team performance. CQ Net (2019) https://www.ckju.net/en/dossier/team-mental-models-increase-team-performance (2019).
19. Outland, N.B.: A Computational Cognitive Architecture for Exploring Team Mental Models. College of Science and Health Theses and Dissertations. 289. https://via.library.depaul.edu/csh_etd/289 (2019).

20. Seo, S., Kennedy-Metz, L.R., Zenati, M.A., Shah, J.A., Dias, R.D., Unhelkar, V.V.: Towards an AI coach to infer team mental model allignment in healthcare. Department of Computer Science, Rice University Houston TX, USA (2021).
21. Shih, Y.F. Alessi, S.M.: Mental models and transfer of learning in computer programming. Journal of Research in Computing Education, 26(2), 154-175 (1993).
22. Stelmaszczyk, M. (2016). Relationship Between Individual and Organizational Learning: Mediating Role of Team Learning. Journal of Economics and Management, 26(4), 1732-1947. https://doi.org/10.22367/jem.2016.26.06
23. Todd, J.: Audit of compliance with WHO surgical safety checklist and building a shared mental model in the operating theatre. BJM Leader 2(1), 32-135 (2018).
24. Treur, J.: Modeling Higher-Order Adaptivity of a Network by Multilevel Network Reification. Network Science 8, S110-S144 (2020a).
25. Treur, J.: Network-Oriented Modeling for Adaptive Networks: Designing Higher-Order Adaptive Biological, Mental and Social Network Models. Springer Nature, Cham (2020b).
26. Treur, J., Van Ments, L. (eds.) (2022), Mental Models and their Dynamics, Adaptation, and Control: a Self-Modeling Network Modeling Approach. Springer Nature, to appear (2022)
27. Turi, J.A., Sorooshian, S. (2019). The impact of organisational structure on organisational learning. Middle East J. Management. 6(2), 204-232.
28. Van Gog, T., Paas, F., Marcus, N., Ayres, P., Sweller, J.: The mirror neuron system and observational learning: Implications for the effectiveness of dynamic visualizations. Educational Psychology Review 21(1), 21-30. (2009).
29. Van Ments, L., Treur, J.: Reflections on Dynamics, Adaptation and Control: a Cognitive Architecture for Mental Models. Cognitive Systems Research 70, 1-9 (2021c).
30. Van Ments, L., Treur, J., Klein, J., Roelofsma, P.H.M.P.: A Computational Network Model for Shared Mental Models in Hospital Operation Rooms. In: Proceedings of the 14th International Conference on Brain Informatics, BI'21. Lecture Notes in AI, Springer Nature. (2021a)
31. Van Ments, L., Treur, J., Klein, J., Roelofsma, P.H.M.P.: A Second-Order Adaptive Network Model for Shared Mental Models in Hospital Teamwork. In: Nguyen, N.T., et al. (eds.), Proc. of the 13th International Conference on Computational Collective Intelligence, ICCCI'21. Lecture Notes in AI, Springer Nature (2021b).
32. Wilson, A.: Creating and applying shared mental models in the operating room. Journal of perioperative nursing 32(3), 33-36 (2019).
33. Wiewiora, A., Smidt, M., Chang, A. (2019). The 'How' of Multilevel Learning Dynamics: A Systematic Literature Review Exploring How Mechanisms Bridge Learning Between Individuals, Teams/Projects and the Organization. European Management Review 16, 93–115 (2019).
34. 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 (2020) 201–214
35. Yi, M.Y., Davis, F.D.: Developing and validating an observational learning model of computer software training and skill acquisition. Information Systems Research 14(2), 146-169. (2003).