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Multilevel organisational learning in a project-based organisation: computational analysis based on a 3rd-order adaptive network model

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Abstract

This paper describes how the recently developed self-modeling network modeling approach for multilevel organisational learning has been tested on applicability for a real-world case of a project-based organisation. The modeling approach was able to successfully address this complex case by designing a third-order adaptive network model. Doing this, as a form of further innovation three new features have been added to the modeling approach: recombination of selected high-quality mental model parts, refinement of mental model parts, and distinction between context-sensitive detailed control and global control.

Keywords: multilevel organisational learning, adaptive computational model, project-based organisation

1. Introduction

An organisation's ability to acquire learning from individuals and teams is important for its capability building and long-term survival. Multilevel organisational learning focuses on learning processes that connect individuals, teams

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and organisation, and has been an established area of research (Kim, 1993; Crossan, Lane, White, 1999; Iftikhar and Wiewiora, 2021; Wiewiora, Smidt, Chang, 2019; Wiewiora, Chang, Smidt, 2020).

Organisational learning begins with individuals. Individual learning resides in individual's minds through their mental models, which can be described as deeply held internal images of how the world works (Senge, 1992). Learning is activated when individual mental models are changed, for example during discussions, observations, negotiations or imitations of others. Often exchange of diverse individual mental models is activated with the change or adjustment of insights, which in turn results in new learning (Kim, 1993). Organisational members are exposed to social networks, hence are in the position to exchange diverse mental models and create new learnings (Bogenrieder, 2002). Organisational learning is created once individual mental models are shared and sufficiently spread throughout the organization (Kim, 1993). Organisational learning can occur in feed-forward and feedback directions. Feed-forward learning occurs from individuals to teams and to the organisation. It can be activated by individuals sharing their mental models to create new learnings and institutionalising these learnings on the organisational level in a form of routines, processes, or guidelines. Feedback learning occurs from organisation to teams and to individuals and relates to exploiting existing and institutionalized knowledge by the teams and individuals (Crossan et al., 1999). Literature on multilevel organisational learning has been explored in management and organisational studies, and consists of mostly conceptual, exploratory and qualitative work. Only limited and recent work has begun investigating multilevel learning using computational analysis (Canbaloğlu, Treur, Roelofsma, 2022a; Canbaloğlu, Treur, Wiewiora, 2022b; Canbaloğlu, Treur, Wiewiora, 2022c).

Building on previous work on self-modeling networks and mental models (Treur, 2020a, 2020b; Treur and Van Ments, 2022), recently an adaptive dynamical systems modeling approach has been developed that offers a platform for addressing multilevel organisational learning computationally (Canbaloğlu, Treur, Roelofsma, 2022a; Canbaloğlu, Treur, Wiewiora, 2022b; Canbaloğlu, Treur, Wiewiora, 2022c). In the current paper, this approach is applied to computationally analyse a real-world case for a large worldwide project-based organisation, as described in Wiewiora, Chang, Smidt (2020). As such, this research seeks to answer the following research question: how can computational modelling be used to capture multilevel learning in the real-world project-based learning scenario?

Within the computational analysis addressed here, a number of new special features are introduced. One of these special features is that from sets of available mental models, in an informed manner the best quality mental model parts are selected and (re)combined into new mental models, which provides a kind of creative process that has some inspiration from and similarity to evolutionary recombination. Another special feature is that refinement of mental models is used to increase their quality by replacing tasks that occur in the mental model by a sequence of two (or more) simpler subtasks. Finally, yet another special feature is that detailed control and global control over the learning processes are distinguished from each other. To this end, adopting the self-modeling network approach (Treur, 2020a, 2020b), the following four different representational and computational levels are distinguished in the organisational learning processes:

- the base level with mental states playing a role (usually describing tasks) in the considered mental models and the dynamics of these states, for example, based on internal simulation or observation
- the first-order self-modeling level where states are used to explicitly represent the weights of the connections in mental models and their adaptation, recombination and refinement over time within the different learning processes
- the second-order self-modeling level with states that control the learning processes in a detailed, context-sensitive manner
- the third-order self-modeling level with states that control the learning processes globally

Section 2 of this article provides a background knowledge on multi-level organisational learning in the context of a project-based organisation. Section 3 briefly summarises the self-modeling network modeling approach used in this research. Section 4 introduces the third-order adaptive computational network model. In Section 5 an example of a learning simulation, which demonstrates how learning is transferred between the levels, is discussed. Section 6 discusses results from the simulation and outlines research contribution. Section 7 is an appendix with a full specification of the introduced network model.

2. Multilevel organisational learning in the context of a project-based organisation

The vast majority of organisational learning resides in individuals' mental models, which are deeply held believes about the world. This process of organisational learning involves: (1) making explicit an individual's mental model, and (2) providing space for individuals to exchange diverse and even conflicting mental models to create shared mental models (Kim, 1993; Bogenrieder, 2002). 'As mental models are made explicit and actively shared, the base of shared meaning in an organisation expands, and the organisation's capacity for effective coordinated action increases' (Kim, 1993, p. 48). In a parallel literature Craik (1943) noted that mental models are considered as relational structures that are learned and used for internal simulation in order to predict what happens next. Van Ments and Treur (2021) expand on these insights and describe a cognitive architecture for handling mental models. This cognitive architecture consists of three levels: (1) for dynamics of mental models by internal simulation or observation, (2) for adaptation of them, and (3) for control of the adaptation. For more details of application and computational formalisation of this cognitive architecture, see (Treur and Van Ments, 2022). In this (network-oriented) formalisation, mental models are represented as subnetworks within a network with nodes for mental states and connections for their relations. Adaptation of these relations takes place using a (first-order) self-modeling level in the network with self-model states representing the connection weights and control of this adaptation is modeled by a second-order self-model level in the network; see Section 3 or (Treur and Van Ments, 2022) for more details about this.

Project-based organisations offer a rich and complex context to demonstrate how multilevel learning occurs. Most organisations conduct at least some aspects of their work by projects and can be described as project-based. Projects are temporary endeavours, set up to create a novel product, service or process. The multidisciplinary nature of projects, in which experts from various areas come together to develop a new solution, provides a vast opportunity for learning. However, due to project temporality, these learnings are often difficult to capture (Bakker, Cambré, Korlaar, Raab, 2011). This is because a project team disbands right after the project is delivered and they take valuable learnings with them. Mature project-based organisations deploy project management offices (PMOs) to assist projects in capturing learnings and transferring these learnings to the organisation or other projects (Pemsel, Wiewiora, 2013). A PMO is a department or unit within on organisation that provides support to managing projects including development of project management standards, providing training and coaching to project managers (Project Management Institute, 2013). For the case considered here, organisation Alpha is a large and global project-based organisation (all names have been replaced by anonymous ones). Alpha has 24 PMOs across its regions. In Alpha, members of the PMOs meet virtually on a regular basis to share learnings from their respective regions with the attempt to institutionalise that learning and improve project management practices. These formal meetings are called PMO Forums and provide opportunity for networking. The case addressed here, has been described in Wiewiora, Chang, Smidt(2020). Below, the example of multilevel learning involving projects and PMO is presented in sequences. Learning artefact that is being developed is *a risk management practice.*

- In one of the PMO forums, members discussed approaches to capture and manage risks. PMO manager from USA – Roger (pseudo name) shared a risk management practice with the PMO network
    - This risk management practice was developed locally, by the project managers from Roger's location. The practice was created through face to face and small team meeting amongst project managers. As such, Roger organised a meeting with the local project managers and asked them to share their individual risk-management practices. This way he provided project managers opportunity and space for sharing their mental models and interpreting of learning.
    - Roger then took the best parts from different solutions to create one risk-management process. This demonstrates evidence of initial institutionalisation of the learning practice on the local level. At present, this risk management approach is considered the best practice and allows to capture risk in a systematic and effective way.
- At the PMO forum, other PMO members begun sharing risk management practices from their own locations.
- At the subsequent PMO forum, PMO personnel begun drawing upon these practices and developed an improved version of the risk management practice that can be used by the entire organisation.

- PMO Central took charge of this improved version and converted to a global risk management practice, which now can be used across the locations. This demonstrates evidence of institutionalisation of learning on the organisational level.

This example demonstrates team level learnings: (1) informal between project managers, and (2) formal between PMO personnel at the PMO forum. It also demonstrates how the learning is institutionalised into a new practice, first on the local and later on the organisational level. In Fig. 1 a conceptual overview is shown to illustrate the addressed scenario. Table 1 provides an overview of this scenario with some interpretations in terms of organisational learning processes.

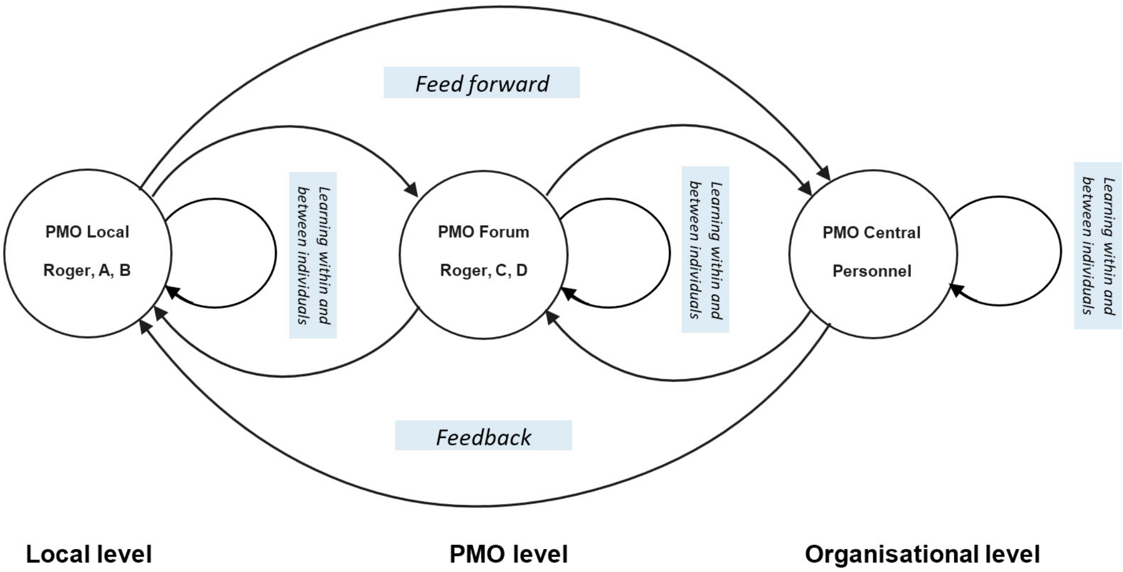

Fig. 1 Conceptual overview of the processes involved in the multilevel organisational learning case addressed. Here at the PMO Local level, A and B are project managers working in the local area with Roger as the PMO manager, whereas at the PMO Forum level, C and D are representatives of managers from other PMO departments.

Table 1 Fragments of the considered case scenario with interpretations

Level	Scenario fragments	Interpretations
PMO Local	• The practice was developed locally, by the project managers from Roger's location. The practice was created through face to face and small team meeting amongst project managers. As such, Roger organised a meeting with project managers and asked them to share their individual risk-management practices. • Roger then took the best parts from different solutions to create one risk-management approach.	Feed forward learning by (re)combination of best mental model parts: Individual mental models of local team members → Shared local team mental model Feedback learning: Shared local team mental model → Adjustment of the individual mental models of members
PMO Forum	• At the PMO forum, other PMO members begun sharing risk management practices from their own locations. • At the subsequent PMO forum, PMO personnel begun drawing upon these practices and developed an improved version of the risk management practice that can be used by the entire organisation.	Feed forward learning by (re)combination of best mental model parts: Individual mental models of PMO Forum members → Shared mental model for PMO Forum Feedback learning: Shared PMO Forum mental model → Adjustment of mental models for PMO Forum
PMO Central	• PMO Central took charge of this improved version and converted to a global risk management practice, which now can be used across the locations.	Feed forward learning by refinement: Shared mental model for PMO Forum → Shared mental model for organisation Feedback learning: Institutionalised learning → Change of practice for organisation, team and individuals

3. The self-modeling network modeling approach used

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

- *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 canonical difference (or related differential) equations are used for simulation purposes; they incorporate these network characteristics $\boldsymbol{\omega}_{X,Y}$, $\mathbf{c}_Y(..)$, $\boldsymbol{\eta}_Y$ in a standard numerical format:

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

for any state Y and where X_1 to X_k are the states from which Y gets its incoming connections. The available dedicated software environment described in (Treur, 2020, Ch. 9), includes a combination function library with currently around 50 useful basic combination functions. 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 combination functions that are applied in the model introduced here can be found in Table 2.

Table 2 Examples of combination functions for aggregation available in the library

	Notation	Formula	Parameters	Used for
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	All states except X_{48}-X_{50}
Steponce	$\mathbf{steponce}_{\alpha,\beta}(..)$	1 if time t is between α and β, else 0	Start time α; end time β	Context states X_{48}-X_{50}

The two combination functions as shown in Table 2 and available in the combination function library are called *basic combination functions*.

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 network-oriented conceptualization 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 $\mathbf{W}_{X,Y}$; such states are shortly called **W**-states. 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 $\mathbf{H}_Y$ (an **H**-state). Such added self-model states are integrated in the network and therefore have their own incoming and outgoing connections. As an example, also connections between different **W**-states can be used, for example, a connection from a first-order self-model state $\mathbf{W}_{V,W}$ to another first-order self-model state $\mathbf{W}_{X,Y}$. A multitude of such connections between **W**-states are actually used in the adaptive network model introduced in Section 4 to model how one mental model can be influenced by (or learned from) another one. 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 $\mathbf{W}_{\mathbf{W}_{V,W},\mathbf{W}_{X,Y}}$ representing the weight $\boldsymbol{\omega}_{\mathbf{W}_{V,W},\mathbf{W}_{X,Y}}$ of the connection from first-order self-model state $\mathbf{W}_{V,W}$ to first-order self-model state $\mathbf{W}_{X,Y}$, which in turn represent the weights $\boldsymbol{\omega}_{V,W}$ and $\boldsymbol{\omega}_{X,Y}$ of the connections from base state V to W and from base state X to Y, respectively. These types of second-order self-model states, shortly called $\mathbf{W}_{WW}$-states or higher-order $\mathbf{W}$-states, are used in the introduced adaptive network model as a way to control multilevel organisational learning in a detailed manner. In the network model also third-order self-model states are used to obtain global control over the phases of the organisational learning: $\mathbf{H}_{WWW}$-states representing the speed factors of the $\mathbf{W}_{WW}$-states. This makes the introduced model a third-order adaptive network model.

4. The designed controlled adaptive network model

The designed network model for the project management organisation PMO described in Section 2 is adaptive to address the different forms of multilevel organisational learning involved and in addition explicitly addresses global and detailed context-sensitive control over the different organisational learning processes. There are three different contexts with actors that play a main role:

- **Roger's own location L.** Roger is communicating with project managers from that location. Two examples A and B of such project managers are included in the model. Roger selects the best parts of their individual mental models to form an improved mental model by some form of recombination. This becomes a shared team mental model at the location (local feed forward learning at location L); based on this A and B improve their individual mental models (local feedback learning at location L)
- **The PMO Forum F.** Here Roger communicates with representatives from other PMO departments. Two examples C and D of such representatives are included in the model. Roger and the other members use the best parts of their individual mental models to obtain an improved shared mental model for forum F (feed-forward learning at PMO Forum F); based on this, C and D improve their individual mental models (feedback learning at PMO Forum F)
- **PMO Central P.** At this level of organisation, the PMO personnel, by refinement adds further improvements to the shared mental model from PMO Forum F. The resulting mental model is proposed to be institutionalised as a shared mental model for the project-based organisation as a whole (feed forward learning at the organisation level).

In the designed model, the mental models for the three different contexts have three different representations (indicated by namings R-L, PMO-F and PMO-P, respectively). The specific example mental models used in the model have multiple sequential branches (indicated by tasks a and b with subscripts) that can be followed in parallel as preparation for a final task c. Two types of operations on mental models have been addressed:

- **Recombination:** Taking specific branches of different mental models and combine them to obtain another mental model; this operation is used at the local level L and in the forum F
- **Refinement:** Refining one branch by splitting one task b into two tasks bi and bii; this operation is used by PMO Central to obtain the final proposal to be institutionalised

To structure the process, as a form of global control the different contexts have been addressed according to three different phases:

Phase 1: Local PMO
Communication at Roger's location of the individual mental models of A and B to Roger and aggregation of them by incorporating the best parts of them to obtain a shared mental model of the location (feed forward learning) and learning from this shared mental model (feedback learning).

Phase 2 PMO Forum
Communication at the PMO Forum F of the individual mental models of C and D and Roger, aggregation of them (feed forward learning), and learning from the resulting shared mental model (feedback learning).

Phase 3 PMO Central
By PMO Central personnel improving the individual mental model from forum F to obtain a proposal for institutionalisation (feed forward learning)

Fig. 2 depicts the adaptive network model. At the base level (pink plane) for each person or team a subnetwork (in total seven of them) is included that as an illustrative example represents (as discussed in Section 2) the mental model's relational structure of the assumed mental model for a person or team. Here mental model states are depicted by nodes and the relations between these mental model states by connections. For the example, as illustration each mental model consists of an end state for task c, with a number of branches to it (indicated by tasks a and b with subscripts); these branches are also called mental model parts. In this way, from left to right, the following can be seen in the lower (pink) plane in Fig. 2:

- the three mental model structures for A, B, and Roger (R-L) for Roger's local situation: light pink nodes
- the three mental model structures for C, D, and PMO Forum (PMO-F) for the forum: darker pink nodes
- the mental model structure for the PMO Central personnel PMO-P: purple nodes
- the three context states con_{ph1} (light pink) for Phase 1, con_{ph2} (darker pink) for Phase 2, and con_{ph3} (purple) for Phase 3; these will be used as input for the global control level to initiate and control these phases

Note the difference between solid arrows and dotted arrows in Fig. 2. The solid ones indicate connections that in the scenario used are initially known already, whereas the dotted arrows indicate connections that are learned during the process. The mental model states have activation levels that vary over time from 0 (not activated) to 1 (fully activated). Based on this, internal simulation takes place by assigning for each of the mental models' activation levels 1 to the (left-hand) states for task a and then by propagating the activation to next connected states in the mental model network structure.

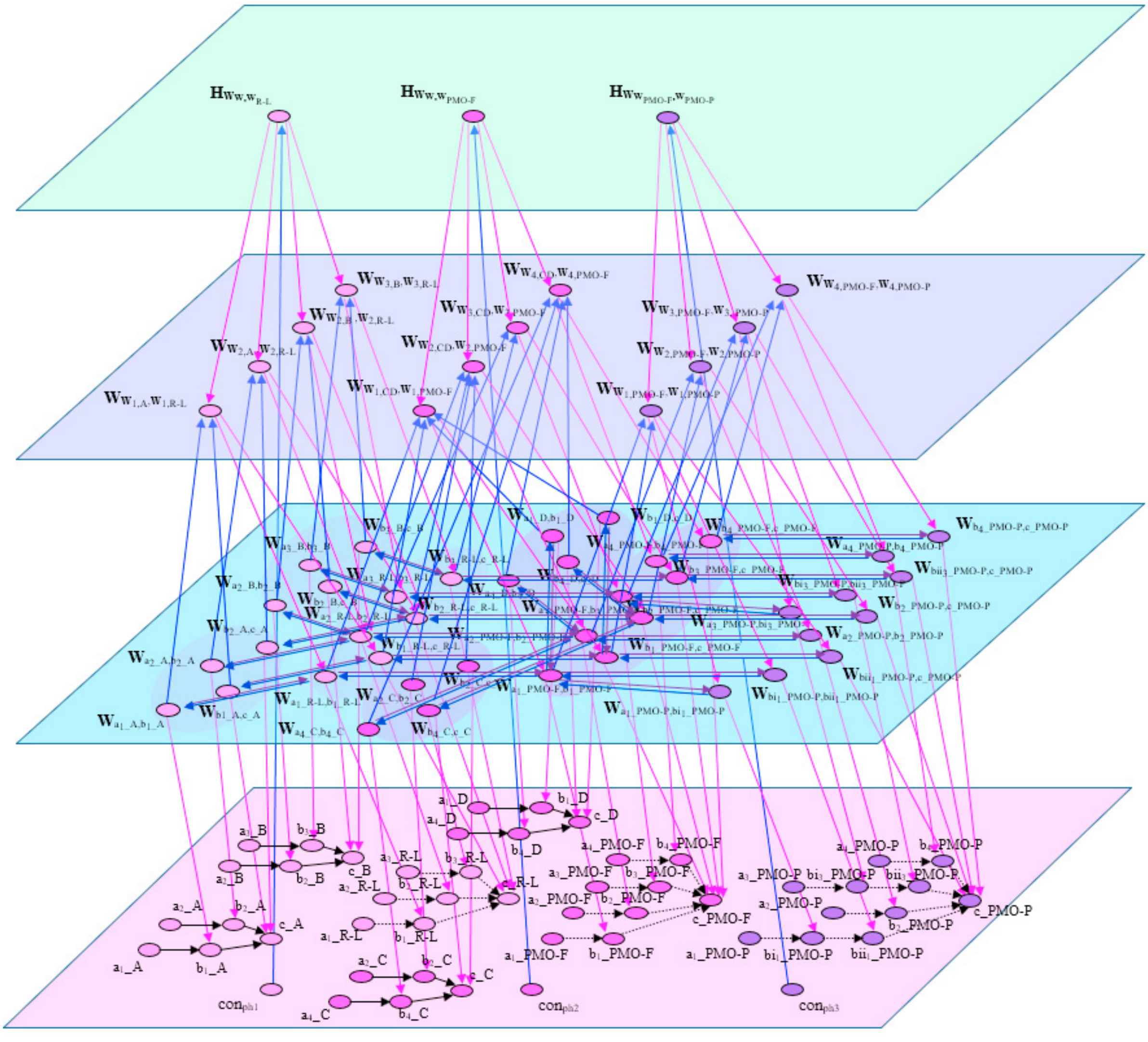

Fig. 2. The overall third-order adaptive network model: base level for mental model states involved and their internal simulation (pink plane), level for learning of the mental model connections (blue plane), level for detailed control of the learning of the mental models (purple plane) and global control level for the three different phases (green plane)

In the middle (blue) plane in Fig. 2 the learning processes are addressed, thereby not yet considering the control of these learning processes. For each of the connections of the different mental models (depicted as arrows in the pink base plane in Fig. 2), a self-model **W**-state is introduced that represents the weight of the connection. The **W**-states have activation levels between 0 and 1. Here 0 means no knowledge about this connection and 1 full knowledge; intermediate values mean having partial knowledge. The **W**-states provide an additional level of representation of mental models on top of that at the base level. For example, at the base level, A's mental model (at Roger's location) has 4 connections and the cluster of **W**-states for this mental model is $\mathbf{W}_{a1\_A,b1\_A}$, $\mathbf{W}_{b1\_A,c\_A}$, $\mathbf{W}_{a2\_A,b2\_A}$, $\mathbf{W}_{b2\_A,c\_A}$. The slightly darker shaded big ovals in the blue plane in Fig. 2 indicate 6 of such clusters, each belonging to one mental model. By the pink downward arrows from the blue plane to the pink plane it is specified that the values of these self-model **W**-states are used for activation of the related mental model states during the internal simulation processes at the base level.

Within the (first-order) self-model, connections between different **W**-states (belonging to different mental models) are used for the organisational learning processes. These (horizontal) connections from left to right in the blue plane in Fig. 2 are used for feed forward learning processes and the connections in the opposite direction for feedback learning processes. These connections can also be interpreted as communication or transfer channels by which the knowledge represented by the concerning (source) **W**-state at the starting point of the arrow is transferred to the other (destination) **W**-state at the end point of the arrow, thereby being aggregated with knowledge from other incoming arrows (by the logistic combination function indicated in Table 2).

As described above, the horizontal connections between the **W**-states are the basis for the learning of the mental models. However, within an organisation such connections are not automatically used. Such pathways may potentially be present but can be left inactive due to different contextual circumstances, including leadership styles and related management decisions. To cover this essential aspect as well, two other self-modeling levels were added to the network model for the control of the learning. Here in Fig. 2 the purple plane models detailed control decisions for the different channels between **W**-states. These control decisions address the choice of mental model parts to be included in the feed forward learning processes. For example, the second-order self-model state $\mathbf{W}_{\mathbf{W}1\_A,\mathbf{W}1\_R\text{-}L}$ models the decision to let model part 1 of A be included in the mental model built locally by Roger (R-L). To this end it represents the weight of the connection (or channel) from $\mathbf{W}_{a1\_A,b1\_A}$ of A's mental model to $\mathbf{W}_{a1\_R\text{-}L,b1\_R\text{-}L}$ of Roger's local mental model. The blue upward connections from the blue plane to the purple plane assure make that this $\mathbf{W}_{\mathbf{W}1\_A,\mathbf{W}1\_R\text{-}L}$ is only activated if the mental model connection of A represented by $\mathbf{W}_{a1\_A,b1\_A}$ is strong and not in case of a weak connection. This creates a selection of strong mental models and lets weak mental models out of consideration within the feed forward learning process. By the downward pink arrows from the purple plane to the blue plane these decisions are effectuated, so that the related channels between **W**-states are actually opened.

Finally, in the top level (green) plane in Fig. 2, a form of overall control is modeled concerning the different phases of the addressed scenario. On this highest level there are the three $\mathbf{H}_{\mathbf{WWW}}$-states that control the adaptation speed of the $\mathbf{W}_{\mathbf{WW}}$-states based on the considered context; here this context is modeled based on the three context states in the base level for Phase 1 to 3. The long blue upward arrows from lowest to highest level indicate how these $\mathbf{H}_{\mathbf{WWW}}$-states adapt to a given context at hand. Once activated, they in return activate the corresponding states in the second-order self-model level (purple plane) via their downward pink arrows. For more details of the model, see the Appendix as Linked Data at https://www.researchgate.net/publication/361312733.

5. Simulation of the scenario

5.1. The learning in the different phases

In the example scenario discussed here, PMO Local for Roger with members A and B is active in Phase 1 from time 20 to time 60 (controlled via the third-order self-model state $\mathbf{H}_{\mathbf{WW},\mathbf{W}_{R\text{-}L}}$)

- Project manager A has a mental model with two parts 1 and 2 (branches) which together prepare for final task c: $a_1 \to b_1 \to c$ and $a_2 \to b_2 \to c$.
- Project manager B has only a mental model with one part 3 (branch) which prepares for final task c: $a_3 \to b_3 \to c$. The states [a_2 b_2 c] are known states but B has no knowledge of relations yet.

From time 0 to time 20 Project manager A is able to successfully use her own mental model. As can be seen in Fig. 3, upon a_1 and a_2 occurring (value 1 for both from time 0 on), both b_1 and b_2 from A's mental model parts 1 and 2 start to increase to around level 0.85 (green line) and due to that c increases to a level close to 1 (lighter green line). Apparently, b_1 and b_2 (even while both have a level not higher than around 0.85) together provide enough preparation to get c done at a high level. For Project manager B it is different.

Although for B state b_3 from B's mental model part 3 also reaches a level around 0.85 (green line), like for b_1 and b_2, this only results in c reaching a level only just above 0.7 (the light brown line initially behind the blue line), as b_3 does not provide enough preparation for c. Apparently, b_3 at a level around 0.85 does not provide enough preparation for good performance for task c. In principle, B also knows of tasks a_2 and b_2 that play a role in A's mental model but he has no knowledge yet about their relations in this phase; therefore he does not use that mental model part 2 to supplement his mental model part 3 based on a_3 and b_3.

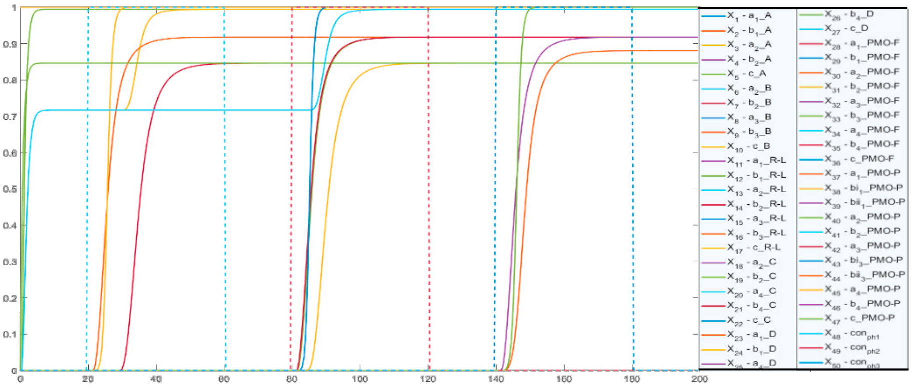

Fig. 3 Base level of the example simulation for the scenario: the internal simulation for the base states

For time 20 to 60, Roger develops an improved mental model for his local PMO group, based on the best parts of the mental models of the group members A and B. He interacts with A and acquires the two good mental model parts of her and adopts these two parts. This can be seen in Fig. 5, where the control $\mathbf{W}_{WW}$-states X_{91} and X_{92} for both parts come up just after time 20 (behind the green line). Similarly, he adopts the mental model part 3 from B, as that looks as strong as each of the mental model parts of A (the same green line). This does not happen for B's potential mental model part 2 as for B this has no knowledge (yet).

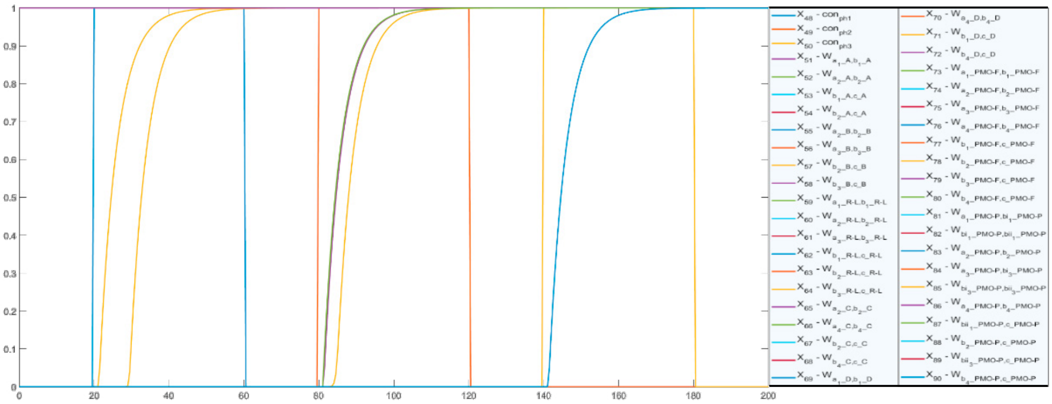

Fig. 4. The adaptation level of the example simulation for the scenario: the first-order self-modeling level **W**-states for the learning on different levels of the organisation

So, Roger has now obtained the following mental model: $a_1 \rightarrow b_1 \rightarrow c$, $a_2 \rightarrow b_2 \rightarrow c$, $a_3 \rightarrow b_3 \rightarrow c$. This learning can be seen in Fig. 4 by the orange line starting just after time 20 (from A for 1 and 2 and from B for 3). Around times 25 to 30, interaction with B takes place about mental model part 2 for B: first the communication about 2 is opened (the purple line starting around 25) and next B is learning mental model part 2 (the orange line in Fig. 4 starting around time 30). As the interactions with A and B are bidirectional, due to that B finally also adopts the mental model part $a_2 \rightarrow b_2 \rightarrow c$ that Roger had obtained from A. Therefore, also for him now b_2 gets a value around 0.85 (the dark red line in Fig. 3 starting around time 25 and joining the green line around time 55). Because of this additional preparation, now also c for B increases to close to 1 (the light brown line in Fig. 3 leaving the blue line just after time 20 and joining the green line close to 1 around time 40).

At the nonlocal level of the PMO Forum, the mental model developed locally by Roger and his locals is one of the inputs, but also the mental models of Forum members C and D. This is an overview of this input:

Roger: $a_1 \rightarrow b_1 \rightarrow c$, $a_2 \rightarrow b_2 \rightarrow c$, $a_3 \rightarrow b_3 \rightarrow c$

Forum member C: $a_4 \rightarrow b_4 \rightarrow c$, $[a_2 \;\; b_2 \;\; c]$ (known states without knowledge of relations yet)

Forum member D: $a_4 \rightarrow b_4 \rightarrow c$, $[a_1 \;\; b_1 \;\; c]$ (known states without knowledge of relations yet)

In Fig. 4 the red line (based on context state con_{ph2} for Phase 2) starting almost vertically at time 80 initiates that all channels from Forum members R-L, C and D to PMO-F (and back) are opened (see also Fig. 5). Soon after that, the **W**-states for the mental model model parts 1 to 3 from Roger and 4 from C and D are transferred to the Forum (the multi-colour curve in Fig. 4 starting immediately after time 80). After that, the orange line in Fig. 4 starting around time 85 indicates the **W**-state of D for learning back mental model model part 1 (previously contributed by Roger) from the forum. In Fig. 3 it can be seen that now D's internal simulation becomes better. The light blue line in Fig. 3 indicates the level of c_D. While based on D's initially available mental model part 4 it was at a lower level just above 0.7 in the period before time 85, it only becomes high (reaching a value close to 1 between 85 and 90) after D has learned additional mental model part 1 at the Forum.

After the previous phase the PMO Forum has knowledge

$$a_1 \rightarrow b_1 \rightarrow c,\ a_2 \rightarrow b_2 \rightarrow c,\ a_3 \rightarrow b_3 \rightarrow c,\ a_4 \rightarrow b_4 \rightarrow c$$

This is used as input for the Forum personnel; the opening of the channel from the PMO Forum to the PMO personnel is shown by the lighter blue line starting at time 140. The personnel decide to improve the model parts 1 and 3 by refining task b into two subtasks bi and bii so that the step from a to b is split into two steps: from a to bi and from bi to bii. Splitting each of the tasks b_1 and b_3 into two subtasks makes that c gets a better preparation and will be more successful. Due to this, the knowledge becomes

$$a_1 \rightarrow bi_1 \rightarrow bii_1 \rightarrow c,\ a_2 \rightarrow b_2 \rightarrow c$$
$$a_3 \rightarrow bi_3 \rightarrow bii_3 \rightarrow c,\ a_4 \rightarrow b_4 \rightarrow c$$

Developing this knowledge is depicted in Fig. 4 by the darker blue line starting just after time 140.

Overall, in Fig. 3 it can be seen that during the process when more mental model parts are learned, the internal simulation becomes better and better. The light blue line in Fig 3 indicates the level of c_D. It only becomes high after D has learned mental model part 1 in phase 2 at the Forum. Similarly, at the local level c_B only becomes high after B learned mental model part 2 from Roger (orange line in Fig. 3).

5.2. How the learning control works

All these learning processes take place in a controlled manner. In Fig. 5 the control states for this are shown. The highest-level states are the three $\mathbf{H}_{\mathbf{WW}}$-states that control the adaptation speed of the $\mathbf{W}_{\mathbf{WW}}$-states based on the considered context, here modeled by Phase 1 (local level, the red block-like curve from 20 to 60) via Phase 2 (from local to Forum level, the blue block-like curve from 80 to 120) to Phase 3 (from Forum to personnel level, the orange block-like curve from 140 to 180). But note that the actual activation of the $\mathbf{W}_{\mathbf{WW}}$-states depends on the information flowing upward from the mental model parts represented by the **W**-states at the level below (the blue upward arrows to the $\mathbf{W}_{\mathbf{WW}}$-states in Fig. 2). This means that only mental model parts that have values that are high enough will be learned.

This is illustrated by the example simulation as follows. Within Phase 1, the green line starting right after time 20 indicates the $\mathbf{W}_{\mathbf{WW}}$-states for the channels used for (feed forward) learning from A and B to Roger, whereas the purple curve starting after time 25 indicates the $\mathbf{W}_{\mathbf{WW}}$-state for the channel for (feedback) learning from Roger to B. This is later than time 20 because first Roger had to learn that mental model part from A before B was able to learn it from Roger. The $\mathbf{W}_{\mathbf{WW}}$-state for the channel between Roger and B for mental model part 2 was only opened when this mental model part 2 for Roger got high values, which is after time 25. Similarly, the orange curve starting immediately after time 80 indicates the $\mathbf{W}_{\mathbf{WW}}$-states for the channels within the Forum, and the blue curve starting just after time 140 indicates the $\mathbf{W}_{\mathbf{WW}}$-states for the channels for the modifications made by the Forum personnel.

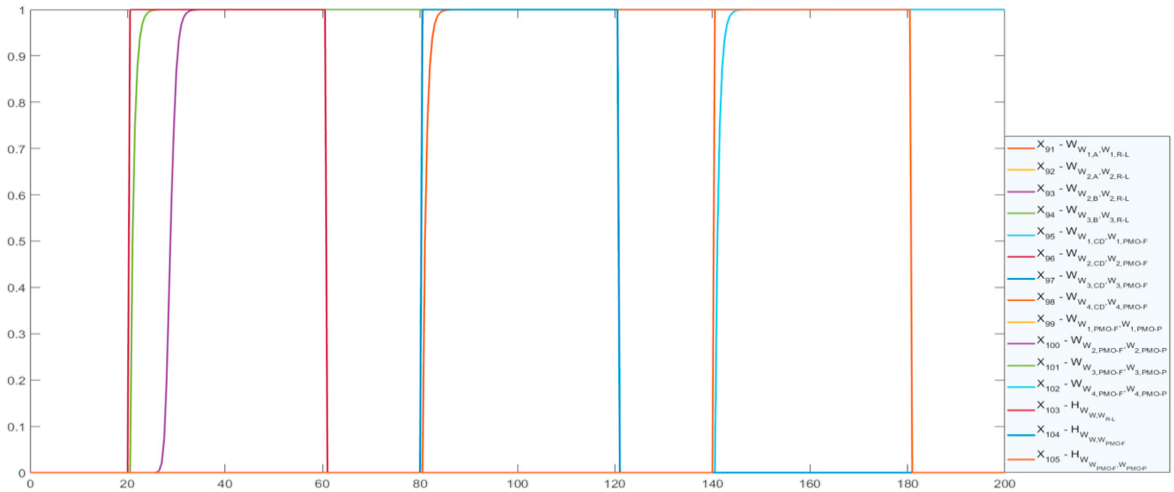

Fig. 5 The control of the adaptations for the example simulation for the scenario: the second-order self-modeling level $\mathbf{W}_{\mathbf{WW}}$-states and third-order self-modeling level $\mathbf{H}_{\mathbf{W_{WW}}}$-states

6. Discussion

This study used computational modelling to capture multilevel learning in the context of a project-based organisation. More specifically, the paper described how a recently developed modeling approach (Canbaloğlu et al, 2022a; Canbaloğlu et al, 2022b; Canbaloğlu et al, 2022c) for multilevel organisational learning has been tested on applicability for the real-world case of a project-based organisation described in Wiewiora et al. (2020). This study offers three useful contributions to theory and practice.

First, this multidisciplinary study uniquely combines insights from management science and computational modeling disciplines to describe and test how learning is transferred from individuals to teams and to organisation, using a learning scenario from the real-world. Studies on organisational learning have recognised that learning occurs on different interacting levels (Crossan et al., 1999) and begun exploring and operationalising learning across different levels using predominantly qualitative methodologies such as interviews or case studies (e.g. Berends, Lammers, 2010; Wiewiora et al., 2020). The field of artificial intelligence and computational modelling has only recently begun using models to describe complex and multilevel social phenomena, with recent work investigating multilevel learning using computational analysis (Canbaloğlu, Treur, Roelofsma, 2022a; Canbaloğlu, Treur, Wiewiora, 2022b; Canbaloğlu, Treur, Wiewiora, 2022c). The current study, presented in this paper, advances existing research by using computational modeling to describe complex learning processes between individuals, teams and organisation.

Second, this study advances the field of computational modelling. Using a designed third-order adaptive self-modeling network model, this research was able to map a complex multilevel learning scenario. During this test, three new features have been added to the modeling approach: recombination of selected high-quality mental model parts, refinement of mental model parts, and distinction between global control and context-sensitive detailed control. This has provided further innovation to the modeling approach as compared to (Canbaloğlu et al, 2022a; Canbaloğlu et al, 2022b; Canbaloğlu et al, 2022c).

Third, the study offers a promising contribution to practice. Computational modeling can assist organisations in making more effective decisions about structuring learning processes. As demonstrated in our scenario, changes to (the settings of) the model can predict changes to the learning outcomes. Therefore, using computational modeling enables to manipulate variables and forecast different learning scenarios, which then provide basis for more informed managerial decisions about providing best conditions for learning.

Future research can utilise self-modeling network modeling approach presented in this study to map different learning scenarios. A new learning scenario can introduce further nuances and additional organisational complexities into the models. This can be done for example, by adding to the models more interactions between individuals and teams, including different leadership styles and organisational cultures, which have been found to influence learning

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