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THE REQUIREMENTS FOR AGENT-BASED LEARNING SYSTEMS IN DESIGN

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Abstract

This paper presents a set of requirements for an agent-based learning system in design, which can be used for future development of the systems. The requirements are derived from a model of collective learning in design that revealed how human designers can interact with and learn from each other. The requirements include aspects of communications, knowledge storage facilities, design activities, learning activities and their links. Communications enable agents to share their knowledge for design and learning. Knowledge storage facilities are the place where agent can store and retrieve their knowledge. Carrying out design activities in a collaborative way provides opportunities for agent-based learning. To perform a learning activity, an agent need input knowledge from other agents and/or itself, mechanisms to acquire and transform knowledge, and mechanisms to trigger learning activities. There also need a mechanism to link design with learning.

Keywords: agent-based learning in design, multi-agent system, collective learning

1 Introduction

An agent in this paper refers to a computing agent, not human beings. Agent-based learning represents the activity of knowledge acquisition that occurs between agents that can communicate with one another, during which knowledge transformation may happen. This paper presents the identification of some generic requirements for agent-based learning systems in design.

Based upon the research framework proposed in [1], a computer model can be developed using the phenomenon model as a basis. A phenomenon model reflects the nature of the "reality" in design, while a computational model is used to develop computer tools to support design. Of course, developing computational tools in turn changes that reality and hence design practice. A model of collective learning in design has been developed [2], that describes how a team of student designers in a team can interact and learn from each other. Final year undergraduate students were chosen for the study due to their availability but also because the students' opportunity for learning is generally greater than for experienced designers. The identified requirements are based upon the developed model.

Currently, there is little work on agent-based learning in design, such as that in [3, 4], which is based upon single function agents. However, the generic requirements and nature of an agent-based learning system in design have not been revealed. Some relevant work can be found in Distributed Artificial Intelligence (DAI) and Computer Supported Collaborative Learning (CSCL). In the domain of DAI, agents can learn to coordinate their actions [5], and learn to communicate [5]. Also in CSCL, researchers investigated the application of computers to assist learning and on co-learning between computers and human beings [6-9].

Section 2 of this paper presents the strengths and weaknesses of current work on multi-agent learning in DAI, CSCL and multi-agent learning in design. The model of collective learning in design is described in Section 3. In section 4, the generic requirements for the development of agent-based learning system in design are identified. Section 5 presents the conclusion of the paper.

2 Current work

Multi-agent learning in DAI has been an active subject since the 1990's [5, 10-13]. Multi-agent systems typically are intended to act in large, open, dynamic and unpredictable environments. For such environments it is impossible to correctly and completely specify these systems *a priori*. Thus, it becomes necessary to endow agents with learning ability to improve their own and overall system performance. Agents can learn to coordinate agent actions [5], learn about and from other agents [10-12]; and learn to communicate [5].

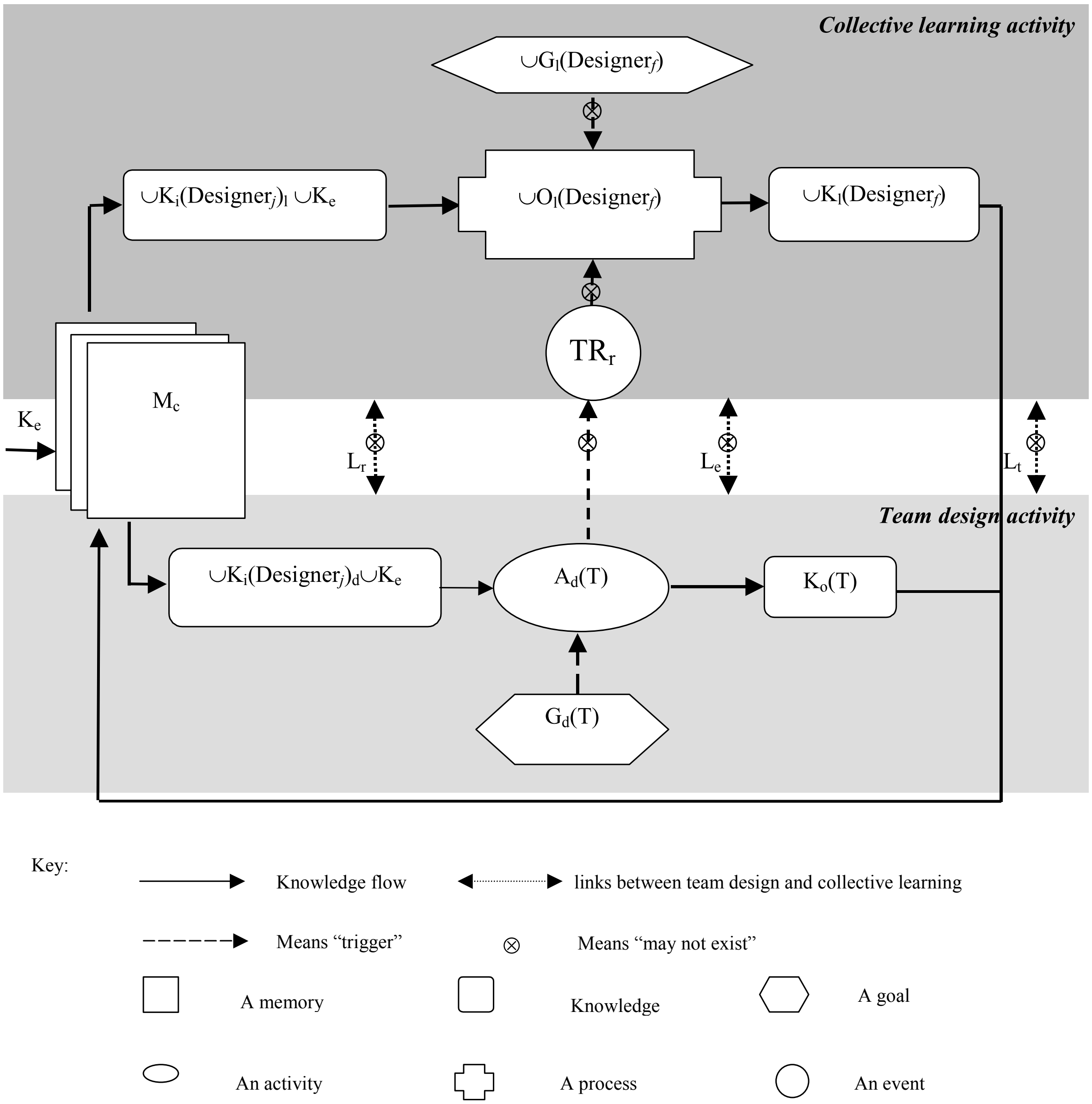
Research in CSCL has the focus on using computers to assist learning and on co-learning between computers and human beings. Theories of collaborative learning, distributed cognition, and situated cognition, and the computing technology of Computer Supported Collaborative Work (CSCW) are employed [6]. Computers play as media of communications between learners, stimulus or catalysts for discussion of competing solutions [7], participants in problem solving [8], and facilitators for distributed cognition [9].

The technologies used in DAI and CSCL such as machine learning techniques, CSCW, and agent-based theories and technologies can be adopted in the context of design to achieve the aim for learning and agent interactions. However, design is considered a special phenomenon with a unique nature and can be considered wicked problem [14]. As such, the requirements for an agent-based learning system in design might be different from those in DAI and CSCL.

Only little research on an agent-based learning system in the domain of design can be found, such as Grecu and Brown's work [3, 4]. They developed agents that can decide, autonomously, that they need to start a learning process. They can reason about where they might find the necessary information to support learning, and they also have criteria to stop a learning process. Thus the agents dynamically interact with their environment. They can also support each other during their learning process. However, the work was based upon single function agents and the generic requirements for agent-based learning in design have not been identified on a scientific foundation.

3 A model of collective learning in design

A model of collective learning in design was developed, based upon existing theories and models in learning and design, and based upon analysis results of protocol data in student team design meeting sessions (see Figure 1) [2]. The model describes the nature of collective learning in team design, and is briefly explained as follows.



M_c – collective memory; $\cup K_i(Designer_j)_d \cup K_e$ – union of input knowledge from student designers and external environment for a team design activity; $\cup K_i(Designer_j)_l \cup K_e$ – union of input knowledge from designers and environment for a collective learning activity; $O_l(Designer_f)$ – learning operator of $designer_f$ (f = 1, …, m, m is the number of designers who perform learning activity); $G_l(Designer_f)$ – the learning goal of $designer_f$; $G_d(T)$ – team design goal; $A_d(T)$ – team design activity; TR_r – rationale trigger; $K_l(Designer_f)$ – learned knowledge of $designer_f$; $K_o(T)$ – output knowledge of team design; L_r – Rationale link; L_e – Epistemic link; L_t – Teleological link.

Note: the key is applied to other figures.

Figure 1 A model of collective learning

3.1 Collective memory

Collective memory is the collection of memories available for team design and collective learning. What is collectively learned is stored in collective memory and can be used for current or future designing and learning. Collective memory provides knowledge sources for team design and collective learning.

3.2 Elements of a team design activity

Team design is the context of collective learning. It is modelled as three elements, namely input knowledge, output knowledge and design goals. Knowledge sources (i.e. input knowledge) needed to carry out a team design activity include those from agents inside or outside a team. Output knowledge is produced as the result of a team design activity. There is a team design goals that represents the purpose of a design activity.

3.3 Elements of a collective learning activity

The model reveals that collective learning exists in team design, although not all team design activities were linked with a learning activity. Designers acquire and transform knowledge from each other through their interactions (e.g. team meetings). The elements of a collective learning activity are modelled as input knowledge, learning goals, rationale[1] trigger, learning operator, and learned knowledge.

One designer or more can learn from others through their interactions. Hence, input knowledge for a collective learning activity is the union of input knowledge from designers, which may include that from the designer who undertakes the learning activity. Input knowledge for a learning activity can be part of or the same as those for the design activity, which indicates the intrinsic links between designing and learning.

A learning goal represents the learning purpose of one or a group of designers, which can originate from a design activity and trigger a learning activity. However, not all learning activities have a learning goal. In some learning activities, designers learned from others only because others verbalised some knowledge, which reflects the human ability of "opportunistic" learning. That is, learning by experience rather than necessity.

Rationale triggers are the reasons that trigger a learning activity. The types of rationale triggers were identified as:

- *Agreement within designers*. Agreed design ideas with some designers could result in others to learn.
- *Disagreement within designers*. Designers can learn when disagreements occur between them.
- *Confirmation from other designers*. The confirmation of a piece of information or ideas can trigger others to learn.
- *Explanation from other designers*. Designers can learn from others from their explanations.
- *Failure of design experience*. Designers can learn lessons from the actual designs and use that learning in future designs.

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[1] "Rationale" is relevant to reasons, while "rational" refers to the ability to reasoning. The word "rationale" is used here to represent the reasons that trigger learning.

– *Successful design experience*. Successful design experience can be learned and used for current or future design practice.

Similar to learning goals, not all learning activities have a rationale trigger. Some designers learn from others only because other designers verbalised some knowledge and they acquire or transform that knowledge.

A learning operator, in a collective learning activity, has the functionality of knowledge acquisition and transformation between different designers, which reside in those designers who undertake a learning activity. When knowledge transformation occurs, the learning transformers described in Table 1 can be applied, which include pairs of opposite meanings of operators, namely generalisation and specialisation, simulation and dissimilation, association and disassociation, agglomeration and decomposition, derivations and randomisation, explanation and discovery, and characterisation and discrimination [15, 16]. It should be noted that there could be more than one agent who learns and might use different learning operators within a design activity.

Table 1 Pairs of knowledge transformers [15, 16]

Generalisation extends the reference sets of input, i.e. it generates a description that characterises a larger reference set than the input.	*Specialisation* narrows the reference set of objects.
Similisation derives new knowledge about a reference set on the basis of the similarity between this set and another reference set about which the learner has more knowledge.	*Dissimilisation* derives new knowledge on the basis of the lack of similarity between the compared reference sets.
Association determines a dependency between given entities or descriptions based on the observed facts and/or background knowledge. Dependency may be logical, causal, statistical, temporal, etc.	*Disassociation* asserts a lack of dependency. For example, determining that a given instance is not an example of some concept is a disassociation transmutation.
Agglomeration groups entities into larger units according to some goal criterion. If it also hypothesises that the larger units represent general patterns in data, then it is called clustering.	*Decomposition* splits a group (or a structure) of entities of into sub-groups according to some goal criterion.
Derivations (reformulation) are transformations that determine knowledge from another piece of knowledge.	*Randomisation* transforms one knowledge segment into another by making random changes.
Explanation derives additional knowledge based upon domain knowledge.	*Discovery* derives new knowledge without an underlying domain knowledge.
Characterisation determines a characteristic description of a given set of entities. For example, a simple form of such a description is a list (or a conjunction) of all properties shared by the entities of the given set.	*Discrimination* determines a description that discriminates (distinguishes) the given set of entities from another set of entities.

The types of knowledge that can be learned individually can also be learned collectively. However there are two types of knowledge identified that can only be learned collectively, namely *common knowledge*, and *knowledge of the knowledge states of other designers*. Common knowledge is defined as the knowledge known by all the designers in a team, which is the result of common learning. A designer can learn the knowledge of which designers have what kind of knowledge. Two or more designers can learn within a design activity. The learned knowledge for a collective learning activity is union of learned knowledge of designers.

3.4 Relations between team design and collective learning

There is a cyclic nature between team design and collective learning. Designers learn collectively during the design process. What is learned can be used for future or current design practice.

A learning activity and a design activity cannot be separated in some situations. The input knowledge and learned knowledge of a learning activity can be part of or the same as the input knowledge and output knowledge of a design activity.

Three types of links between team design and collective learning have been identified, namely teleological, rationale, and epistemic [2, 15]. The teleological link is related to the design goal and learning goal. That is, the design goal can precede the learning goal or vice versa. The rationale link is concerned with different rationale triggers that trigger a learning activity. The epistemic link represents knowledge acquisition and transformation during the design and learning process.

4 The requirements

The requirements for agent-based learning were derived from the model of collective learning in design described in section 3 (i.e. mapping elements of a design and learning activity and their interactions with facilities for computational means). They are detailed with respect to communications, knowledge storage, design activities, learning activities and the linking between them.

4.1 Communications

Agents should be able to communicate with one another to share their knowledge (i.e. input knowledge and learned knowledge). Existing computational networking technologies (e.g. socket communications) and CSCW technologies can support agent communication.

4.2 Knowledge storage

Each agent should be equipped with facilities to store their knowledge. It can be retrieved to perform a design activity or to support a learning activity. There should be two types of memories (individual agent memories and shared memories). Individual memory only stores knowledge that used by individual agents, while shared memory stores knowledge shared by all or more than one agent.

4.3 Requirements to perform design activities

By mapping the elements of a design activity identified in Figure 1 within computational means, the architecture of an agent with design capability is derived (see Figure 2). The components of the agent include the memories, design goal, input knowledge sources, design functionalities, and output knowledge. The agent takes the input knowledge sources, perform the design functionalities and generate output knowledge. Based upon the architecture, the requirements for an agent to perform design activities are detailed as follows:

- An agent should be equipped with knowledge sources to perform a design activity. Agents (e.g. agent A and agent B) should be able to collaboratively share their knowledge when the needs arise. There should be a common language that they could understand each other to enable their communications. Also, the agents should know the knowledge states of other agents so that they could be able to know where they could gain the knowledge they need.
- Agents should have the capabilities to carry out design activities. An agent is specialised in one or more design activity. For each other the design activity, it takes input knowledge and generate output knowledge that could be used as input knowledge for another design activity.
- An agent can have design goals, which is used to initiate a design activity. When an agent can perform two or more design functionalities, the design goals also guide the agent to choose which functionalities to perform in a given situation.
- Agents should know where output knowledge should be stored (e.g. shared memory or individual memories). An agent can be aware of the knowledge that other agents are interested in and store them in a shared memory. As such, an agent should know the interests of other agents.

4.4 The requirements to perform learning activities

By mapping the elements of a learning activity and the interactions of the elements, the architecture of an agent with learning capability is derived (see Figure 3). It includes memories, rationale learning triggers, learning goals, input knowledge, learned knowledge, and knowledge transformation and knowledge storage facilities. An agent uses learning sources as input, runs its learning mechanisms, and produces learned knowledge. The learning mechanism is triggered by a learning goal or a rationale trigger. Based upon the architecture, the requirements for an agent with learning capability are detailed as follows:

- An agent should be equipped with some trigger mechanisms to start a learning task. If an agent can perform several learning tasks, different triggers start different learning tasks. Such triggers can be modelled as learning goals or rationales. Example rationales are successful and failed design experience.
- There should be learning sources that they could share with one another and are used as input for a learning task. An agent should have mechanisms that enable them to share such learning sources. They can also reason about what other agents have the sources they need, when such learning sources are available, and how they could gain them. That is, an agent should know the knowledge states of other agents and the change of knowledge states.
- An agent should be equipped with learning mechanisms to perform learning tasks. The learning mechanisms are used to transform input knowledge into learned knowledge. It is noted that an agent can directly communicate with other agents and acquire a piece of knowledge and store it in their memory. That is, learning can occur without knowledge transformation.

- An agent should have reasoning capabilities to decide where learned knowledge should be stored (e.g. shared memory and individual memories). To enable to do this, an agent should know the interests of other agents .

4.5 The requirements for linking design and learning

The architecture of an agent with design and learning capability is shown in Figure 4, which is based upon the nature of links between design and learning in human designers and the combination of the agents with learning capability and those with design capability (see Figure 2 and Figure 3). Figure 4 shows agents A and B equipped with design and learning capability. Agents A and B have embedded the elements needed to carry out a design activity (i.e. design goal, input knowledge and output knowledge) and those for a learning activity (i.e. input knowledge, learned knowledge, learning goal, knowledge acquisition and transformation mechanisms, rationale trigger). The elements are linked together in the manner explained in sections 4.3 and 4.4. Both agent A and agent B have their own individual memories and they have shared memory. Figure 4 illustrates that what is learned by agents (e.g. agents A and B) can be used as input knowledge for their own or others' design and learning activities, and that the output knowledge from a design activity can be used as input knowledge for their own or others' learning and design activity. The design and learning activity is coupled together and one agent's design and learning activity can be coupled with others' learning and design activities through knowledge sharing among them. Therefore, besides those described in Sections 4.1, 4.2, 4.3 and 4.4, the requirements for an agent with design and learning capability include that an agent should be equipped with the capability to link design with learning. A design activity should be able to automatically trigger a learning task when the need arises. As such, agents can learn their experience of design.

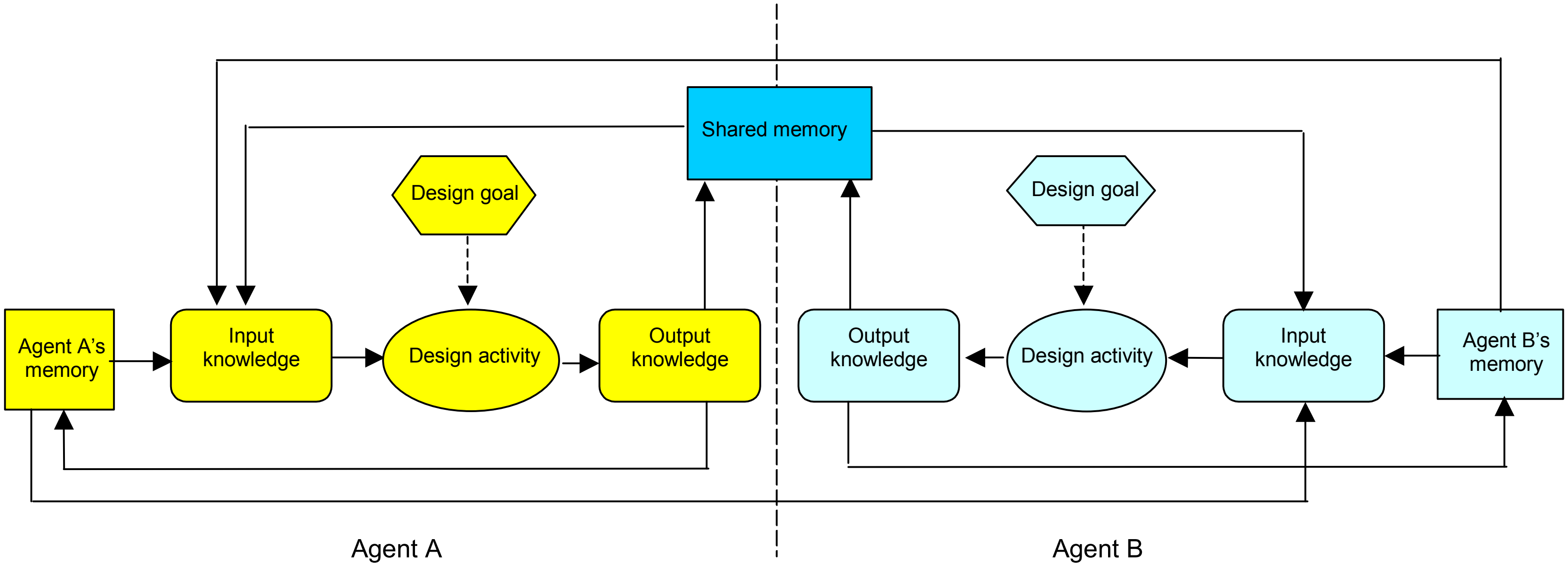

Figure 2 Agents with design capability

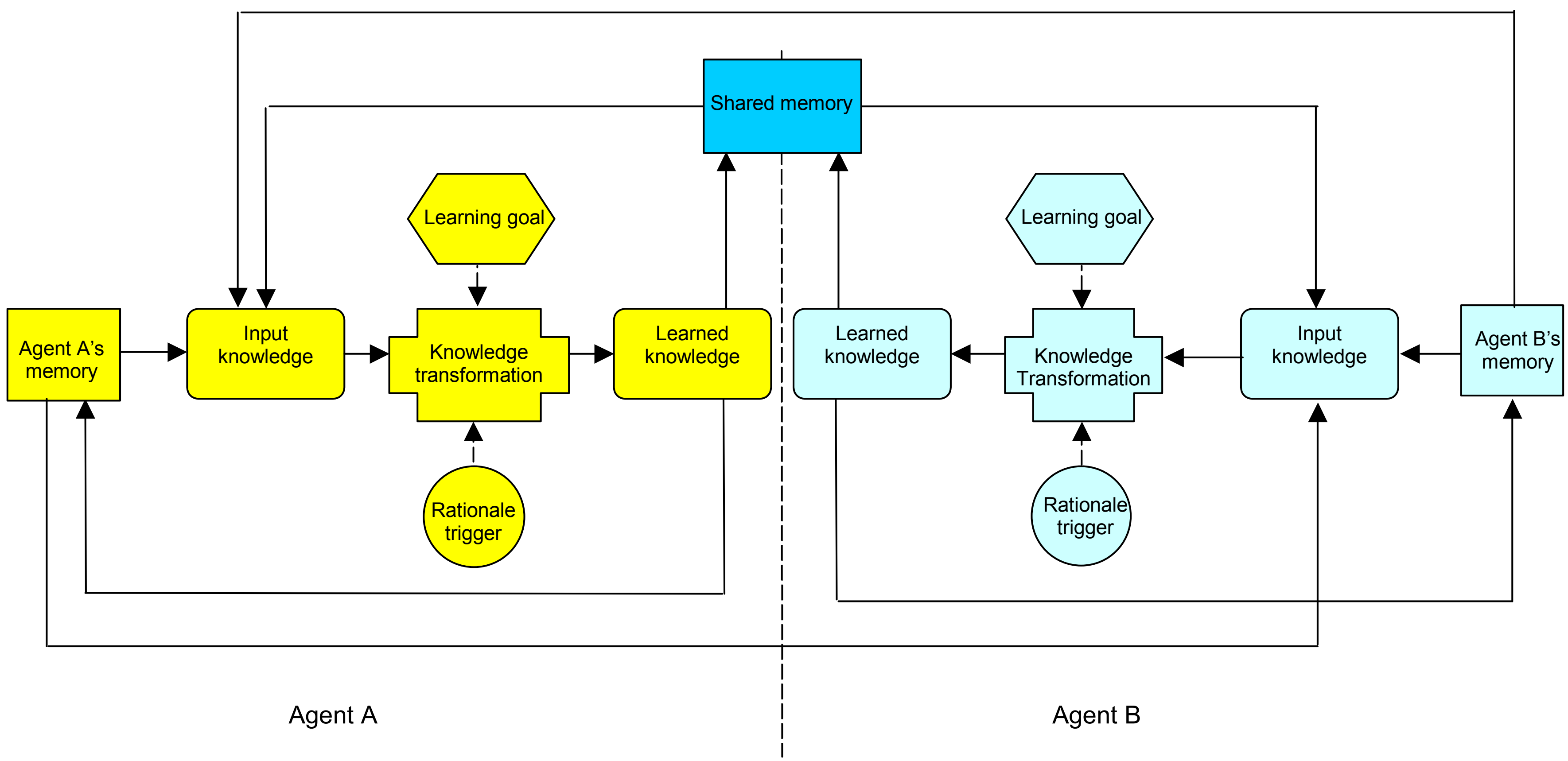

Figure 3 Agents with learning capability

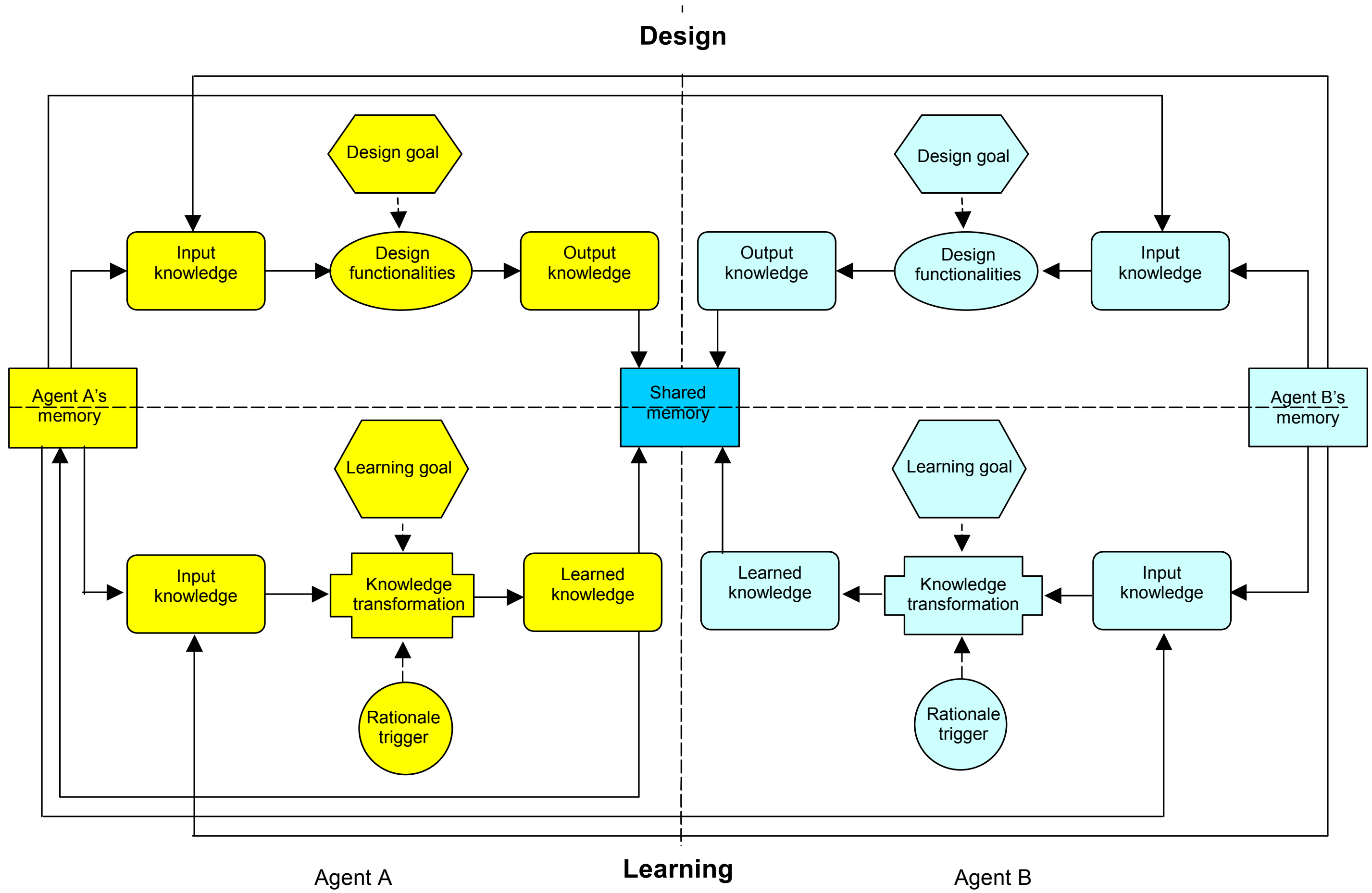

Figure 4 Agents with design and learning capability

5 Conclusion

This paper presents the identification of requirements for multi-agent learning systems in design, which can be used as a basis for the development of future systems. The requirements are derived from the model of collective learning in design, which described how a team of human student designers have interacted and learned from each other [2]. The requirements include aspects of communications, knowledge storage, design activities, learning activities and their links. Agents should be able to communicate with each other so that they could share their knowledge. They should be equipped with knowledge storage facilities where knowledge can be stored and retrieved for both design and learning. The requirements for an agent with design capability can be summarised as:

- Agents should have knowledge sources to perform a design activity.
- Agents should know each other's knowledge states in order to gain the knowledge they required from other agents.
- Agents should be able to perform design activities.
- There should be some mechanisms that trigger an agent to start a design activity.
- Agents should be able to reason about where the output knowledge should be stored (e.g. shared memory and individual memories). That is, agents should know about others' interests.

The requirements for an agent with learning capability can be summarised as:

- Agents should have knowledge sources to perform a learning activity.
- Agents should know each other's knowledge states in order to gain the knowledge sources from other agents to perform a learning task.
- Agents should be equipped with learning mechanisms to carry out learning tasks.
- There should be some mechanisms that trigger an agent to carry out learning tasks.
- Agents should be able to reason about where the learned knowledge should be stored (e.g. shared memory and individual memories). That is, agents should know about others' interests.

To enable an agent to have both design and learning capability, besides the requirements for design and those for learning, there should be some mechanisms that link design with learning.

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