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Modeling of workers' learning behavior in construction projects using agent-based approach

The case study of a steel structure project

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Abstract

Purpose – Learning as the way in which labor acquire new knowledge and skills has important strategic implications for the competitive advantage of an organization. The purpose of this paper is to present an agent-based modeling (ABM) approach to investigate the learning behavior of workers. The effect of interactions among different workers as well as the factors affecting the workers' learning behavior is assessed using the proposed ABM approach.

Design/methodology/approach – For this purpose, the processes through which the competency value of worker is changed are understood and the workers' learning behavior is modeled, taking account of various influencing factors such as knowledge flow, social ability to teach and forgetting factor.

Findings – The proposed model is implemented on a real steel structure project to evaluate its applicability and performance. The variation in the competency value of different workers involved in the project is simulated over time taking account of all the influencing factors using the proposed ABM approach.

Practical implications – In order to assess the effect of interactions among welders as well as the welders' characteristics on their learning behavior, the competence value of different welders is evaluated.

Originality/value – This research presents an ABM approach to investigate the workers' learning behavior. To evaluate the performance of the proposed ABM approach, it was implemented on a real steel structure project. The learning behavior of different welders (agents) was simulated taking account of their interactions as well as the factors affecting the welders' learning behavior. The project involved the welding of a 240-ton steel structure. The initial project duration was estimated as 100 days. In this project, it has been planned to execute the welding process using three different welders namely welder A, B and C.

Keywords Social interaction, Simulation, Labour force, Construction projects, Agent-based modelling, Learning behaviour

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Introduction

Learning is an enduring change in behavior, or in the capacity to behave in a given fashion, which results from practice or other forms of experience (Schunk, 2012). In other words, learning is the way in which people obtain skills and application of new knowledge (Cohen and Levinthal, 1990; Lin and Lee, 2014; Petkovic, 2014) through the promotion of inquiry and dialogue and the creation of continuous learning opportunities (Watkins and Marsick, 1993). Kolb defines learning as the process whereby knowledge is created through the transformation of experience (Kolb, 1984). In fact, learning is viewed as knowledge acquisition through cognitive possessing of information, acquired both from being a part of society and from individual thought process (Young, 2005).

There are various factors affecting the learning process. Learning will occur when there is a discrepancy between the individual's vision and its current reality, and there is a perceived gap. The individuals' understanding of the current reality depends on two main elements. First, the necessary information to perceive the reality should reach the organization's members through interaction among working groups (Huber, 1991; Zagorsek *et al.*, 2009). Second, the individuals should be able to interpret this information properly (Škerlavaj *et al.*, 2007). The organization and management also need to be aware of this discrepancy in the work group (Senge, 2004). If the organization is not aware of the discrepancy, the necessity of learning will not be perceived. Therefore, individuals should believe that learning is an influential way of filling the gap between the current reality and the desired vision (Ghili *et al.*, 2013). The workers will finally commence to learn, after the perception of how the learning can fill the gap.

Learning is an important way for firms to acquire new knowledge and skills (Zander and Kogut, 1995; Dyer and Singh, 1998; Inkpen, 2000). During the last two decades, learning has become a key topic, not only in the areas of psychology, pedagogy and education, but also in organizational and economic contexts and industry (Naylor, 2009). The reason is that learning has important strategic implications for the competitive advantage of a firm (Lieberman, 1987; Kharabsheh, 2007) as well as tactical implications in production (Chand and Sethi, 1990).

The construction industry is undergoing significant changes as it addresses issues such as the introduction of advanced field and office technologies, the aging of the construction workforce, globalization and economic integration in the twenty-first century (Chinowsky and Carrillo, 2007). Therefore, organizations need to develop and innovate given the perceived importance of continuous learning in competition between companies (Drabek, 1974; Hiltrop, 1999; David and Foray, 2002).

There are various studies conducted to investigate the benefits of learning in organizational performance (Azadegan and Dooley, 2010; Kamya, 2012), market orientation and relationship marketing (Santos-Vijande *et al.*, 2005; Stein and Smith, 2009), the strategic supply process (Hult *et al.*, 2007), service quality (Tucker *et al.*, 2007), innovation (Weerawardena *et al.*, 2006), alliance outcomes (Liu *et al.*, 2010) and human resource performance (Budhwar and Bhatnagar, 2007). Empirical studies in several industries have verified the productivity increase as organizations gain experience or knowledge in production, which is referred to as the learning effect (Li and Rajagopalan, 1998). In fact, the outcome of learning is a better understanding by labor of the work responsibilities, improved knowledge, skills and labor productivity (Hijazi *et al.*, 1992).

There are various studies conducted to investigate the workers' learning behavior. Hijazi *et al.* (1992) illustrated the aspects and fundamentals of learning development and its impact on the time requirement of repetitive construction processes from a simulation perspective. Hekel *et al.* (1996) developed an Agent Collaboration Environment to support collaboration learning amongst members of the design team by providing the infrastructure for a community of cooperative design agents that assist the users. Dyer and Hatch (2006) indicated that learning and knowledge sharing within the supplier network of Toyota resulted in better joint performance and hence created competitive advantages for Toyota. Liao *et al.* (2008) conducted a research to explore the relationships between knowledge inertia, organizational learning and organizational innovation. Sessa *et al.* (2010) analyzed a framework of team learning that included the learning processes, the factors that stimulate these processes and consequences of them. Gressgard and Hansen (2014) assessed the relationships between organizations' abilities to learn from failures, knowledge exchange within and between organizational units, quality of contractor relationship management and work characteristics. Rozewski *et al.* (2015) presented a model of collaborative learning in an organizational social network based on knowledge resource distribution through the establishment of a knowledge flow. Givi *et al.* (2015) presented a mathematical model to estimate the human error rate while performing an assembly job under the influence of learning–forgetting and fatigue–recovery.

Although several studies have been conducted to study the learning behavior of workers, they face some major defects. Almost all of the previous works have studied the workers' learning behavior conceptually. The workers' learning behavior, however, has not been modeled quantitatively in the previous works. Therefore, none of the previous studies can investigate how the competency value of workers is changed, taking into account (considering) the effects of their interactions as well as the various factors affecting the workers' learning behavior.

This paper studies the workers' learning behavior using an agent-based modeling (ABM) approach. The effect of interactions among different workers as well as the various factors affecting the workers' learning behavior are assessed using the proposed approach. To account for the effects of workers' interaction on their learning behavior, local interaction rules are defined among workers. The various influencing factors including forgetting factor and social ability to teach are also taken into account using the proposed approach.

Finally, the proposed agent-based model is implemented in a real steel structure project, and the workers' learning behavior is investigated taking into account the effect of workers' interactions as well as their characteristics.

Research methodology

This research presents an ABM approach to investigate the learning behavior of workers, taking into account the effect of their interactions as well as the workers' characteristics.

ABM has recently become popular to investigate complex systems in many areas ranging from sociology, biology and organizational study, to economics, business and military studies (Macal and North, 2005). Sawhney *et al.* (2003) suggested that the happenings within the construction discipline could be better explained based on the agent-based concept.

In this paper, ABM is used to investigate the learning behavior of workers, taking into account their interactions. ABM is a methodology in which a simulation experiment is constructed around a set of autonomous "agents" that interact with each other and their underlying environment to mimic the real-world scenario that they replicate (Sanchez and Lucas, 2002). In ABM, the goal of the simulation is to track the interactions of the agents in their artificial environment and understand processes through which global patterns emerge (Edling, 1998; Swinerd and McNaught, 2012). An ABM approach, built from the ground-up perspective, provides researchers with a proper standpoint toward complex systems by means of having (Son and Rojas, 2011):

- agents that are situated in an environment and have the ability to learn and adapt;
- local interaction rules among agents; and
- global environment settings.

The previous studies show that the majority of the reviewed works on ABM applications involved the definition of agents and their behavior based on researcher's perspective.

Workers' learning behavior through interaction

Interaction is the process by which an idea is transferred from a source to a receiver with the intention of changing his or her behavior. Such behavioral effects may consist of changes in knowledge and changes in attitude, as well as changes in overt behavior (Marzano, 1998). Interaction is closely linked to successful learning and interacting with others or with information can help clarify concepts, improve problem solving and enhance retention. Learning is not possible without interaction since it is a prime factor for learning (Lei *et al.*, 1999). Without information exchange, employees cannot learn from other experts and the process of knowledge acquisition and sharing would be inhibited (Therin, 2003). Therefore, the interaction among learners plays an important role in fostering effective learning process (Piccoli *et al.*, 2001).

The most important element of the interaction learning process is knowledge flow that is a lasting resource of competitive advantage for organizations (Grant, 1996; Nonaka, 2006; Simaškienė and Dromantaitė-Stancikienė, 2014). Knowledge flow is one of the most valuable resources that firms acquire through network (Dyer and Hatch, 2006; Huggins and Johnston, 2010). In addition, an effective interaction learning process results in competence development.

The nature of human interactions and information flow is affected mainly by the creation of new knowledge and the process of learning at an individual level (Koohborfardhaghighi and Altmann, 2014).

It can finally be concluded that interaction has been proposed as one of the key parts of any learning process. In other words, the higher levels of human–human interaction is (are) solid foundations for collaboration in an organization (Schaf *et al.*, 2009; Rozewski *et al.*, 2015).

Modeling of workers' learning behavior: the case study of a steel structure project

This research presents an ABM approach to investigate the workers' learning behavior. To evaluate the performance of the proposed ABM approach, it was implemented on a real steel structure project. The learning behavior of welders (agents) was simulated, taking into account their interactions as well as the factors affecting the welders' learning behavior.

The project involved the welding of a 240-ton steel structure. The initial project duration was estimated as 100 days. In this project, it had been planned to execute the welding process using three different welders namely welder A, B and C.

To assess the effect of interactions among welders as well as the welders' characteristics on their learning behavior, the competence value of different welders is evaluated. Competence is integrated knowledge, skills and attitudes that can be used at work to perform, which means producing output that support organizational goals (Van Loo and Semeijn, 2004). Competence is a "dynamic capability," which produces an expected sustainable competitive advantage and plays a key role as a gateway to tomorrow's markets (Hamel and Prahalad, 1993). Employees' competence and knowledge are today recognized as of utmost importance to support organization's intellectual capital (Ulrich, 1998; Liebowitz and Megbolugbe, 2003).

Competence can be studied from several perspectives for which viewpoints are fairly divergent on competence definition and competence classification (Van Loo and Semeijn, 2004). In this research, the competence of welders is defined and measured based on ISO9606 and EN287 standards. The welders' competence is defined based on theoretical (technical knowledge) and practical measures. According to ISO9606 and EN287, the weight of theoretical and practical measures is considered as 25 and 75 percent, respectively. For the practical measure, 10 points out of the total 75 points are allocated to the observational tests, and the remained 65 points are given to the practical tests (Table I). The competence value of different welders is finally determined in the range of 0–1.

Tables II and III show how the theoretical and practical competency values are calculated.

Table IV represents the resulted competence value of three welders. As shown, the initial competence of welders A, B and C was determined as 0.28, 0.52 and 0.86, respectively.

Type of measure	Weight
Theoretical measure	25%
Practical measure	Observational test = 10% Practical results test = 65%

Table I. Evaluation of welder's competency

No.	Theoretical competencies	Point
1	The ability to recognize and apply working regulations and codes	10
2	The ability to apply computer in the joints welding system	5
3	The ability to apply technical knowledge	5
4	The ability to plan and read welding blueprints	5

Table II. Evaluation of theoretical competencies

Practical competencies		
No.	Practical results test (1)	Point
1	The ability to create an electric arc using submerged arc welding machine	5
2	The ability to weld joints of Aluminum using MIG.MAG method	5
3	The ability to weld stainless steel joints using MIG.MAG method	5
4	The ability to weld steel pipes joints using MIG.MAG method	5
5	The ability to apply simple and compound beading using MIG.MAG method	5
6	The ability to weld Aluminum joints and its alloys using MIG.MAG method in different forms	5
7	The ability to weld stainless steel joints using WIG method	5
8	The ability to weld joints of ordinary steel pipes using WIG method in different forms	5
9	The ability to weld various types of joints of ordinary steel using WIG method in different forms	5
10	The ability to do simple and compound beading on the ordinary steel sheets using WIG welding	5
11	The ability to create electric arc using WIG welding machine	5
12	The ability to weld joints using oxyacetylene and forehand and backhand welding methods (NL) on the pipes fragments and sheets, and backhand welding method (NR) in different forms	5
13	The ability to weld V gap joints and fixed pipes in all forms	5
No.	(2) Observational test	Point
1	The ability to apply destructive and non-destructive tests of the welded joints	10

Table III. Evaluation of practical competencies

ISO9606 – EN287	Welder A	 B	 C
Competence value	0.28	0.52	0.86
The theoretical competence (25%)	0.20	0.43	0.72
The practical competence (75%)	0.31	0.56	0.90

Table IV. The initial competence value of welders

The competence value of welders can be changed through knowledge sharing, learning, forgetting and other knowledge-related processes (Wilkesmann and Wilkesmann, 2011). Welders can transfer experience and technical knowledge by the knowledge sharing to enhance their competences by taking part in projects and interaction with other welders (Jianyu *et al.*, 2015).

In this research, we focused on the knowledge flow through interaction between welders and its influence on the welders' competence level. It is assumed that the knowledge is transferred between welders A and B using the following equation:

$$R^{B \to A} = S_B \cdot C_B[t] \cdot \alpha_B. \tag{1}$$

Constraints:

$$C_B[t] > C_A[t],$$

where $R^{B \to A}$ is the knowledge transfer from welder B to welder A. S_B is social ability to teach for welder B which is in the range of 0–1. S_B represents the social ability to teach skills which aids in transferring knowledge to the recipient (Rózewski *et al.*, 2015). The values of social ability to teach were determined for three welders by the expert based on the criteria in Table V.

C_B is the competence level of welder B and α represents the interactions between the agents which can have the value of 0 or 1. If the interactions among agents occur, α_i is considered as 1 for three agents. In the case that there is no interaction among the agents, α_i is selected as 0.

As shown in Equation (1), the welder can create learning situation which enhances his skills through his expertise, knowledge, experience and style of social ability to teach in the workplace (Malik *et al.*, 2011). The interactions among the agents can enhance the learning and knowledge creation processes and result in an increased level of competence for workers.

Table VI represents the values of social ability to teach (S_i) and the existence of interactions among the agents (α_i) for the welders A, B and C.

The welder's competence in the time [*t*+1] will be defined using the following equation (Różewski *et al.*, 2015):

$$C_A[t+1] = \left\{ \left(1-\beta_A\right).C_A[t]+\alpha_A.R^{B \to A} \right\}. \tag{2}$$

Table V. The factors affecting the value of social ability to teach

1. Communications	Interpersonal skills, effective speaking, presentation skills
2. Confidence	Building confidence
3. Work effectively in groups	The individual member within a group, the group as a whole
4. Be able to deal with conflict	Emotional intelligence, understanding others
5. Empathize	Understanding others, developing others, leveraging diversity

Table VI. The welder's characteristics and attributes: the values of social ability to teach (S_i) and interactions between the agents (a_i)

		Welder	
Parameters	A	B	C
Social ability (S_i)	0.002	0.003	0.004
Interactions between the agents (a_i)	1	1	1
Age	25	34	41
Level of education	Diploma	Technician	Bachelor
Work experience (years)	3	9	16
Involved in similar work in past	Yes	Yes	Yes

Constraints:

$$C_B[t] > C_A[t],$$

where β_A is the forgetting factor of welder A and represents the ratio of the lost competence level due to forgetting knowledge. $C_A[t]$ is the competence of welder A in the time [t], and $R^{B\to A}$ is the knowledge transfer from welder B to welder A, if $C_B[t] > C_A[t]$. Finally, α represents the existence of interactions among the agents which can have the value of 0 or 1.

As shown in the constraints of Equation (2), the knowledge transmission occurs when technical knowledge or level of competence of agent B is more than agent A. Therefore, this interaction helps welder A to increase his welding competences in conjunction with welder B.

As an example, in the following section, it is shown that how the competence of welder A is determined in the time [t+1] in six different conditions:

(1) $C_A[t] > C_B[\text{t}] > C_C[t] \to C_A[t+1] = (1-\beta_A)\ C_A[t]$

(2) $C_A[t] > C_C[\text{t}] > C_B[t] \to C_A[t+1] = (1-\beta_A)\ C_A[t]$

(3) $C_B[t] > C_A[\text{t}] > C_C[t] \to C_A[t+1] = (1-\beta_A)\ C_A[t] + \alpha_A\ R^{B\to A}$

(4) $C_C[t] > C_A[\text{t}] > C_B[t] \to C_A[t+1] = (1-\beta_A)\ C_A[t] + \alpha_A\ R^{C\to A}$

(5) $C_C[t] > C_B[\text{t}] > C_A[t] \to C_A[t+1] = (1-\beta_A)\ C_A[t] + \alpha_A\ R^{C\to A}$

(6) $C_B[t] > C_C[\text{t}] > C_A[t] \to C_A[t+1] = (1-\beta_A)\ C_A[t] + \alpha_A\ R^{B\to A}$

The value of forgetting factor for different agents is presented in Table VII, which is in the range of 0–1.

After determining the value of model inputs, the proposed agent-based model is implemented on AnyLogic software. The developed model is employed in a real steel structure project, and the effect of workers' interactions and characteristics on their learning behavior is evaluated.

It should be stated that the proposed model has the capability to predict the value of different welders' competencies considering all the influencing factors such as knowledge flow, social ability to teach and forgetting factor.

Results and discussion

The competency value of different agents (welders) is affected by the interactions between agents and the agents' characteristics. In this section, the variation in the competence value of different agents is simulated over time, taking account of the impact of knowledge flow between the agents as well as different influencing factors, and the learning behavior of different agents is predicted using the proposed ABM approach.

Figures 1-3 show how the competency value of different agents is changed over time. It should be stated that the simulation was performed for a period of 100 days to track the learning behavior of different agents throughout the project execution.

The simulated results show that the competence value of agents A and B has been increased gradually over time (Figures 1 and 2). As shown, the competency value of agents

Welder	Value of forgetting (β_i)
A	0.005
B	0.003
C	0.001

Table VII. The value of the forgetting factor for three welders

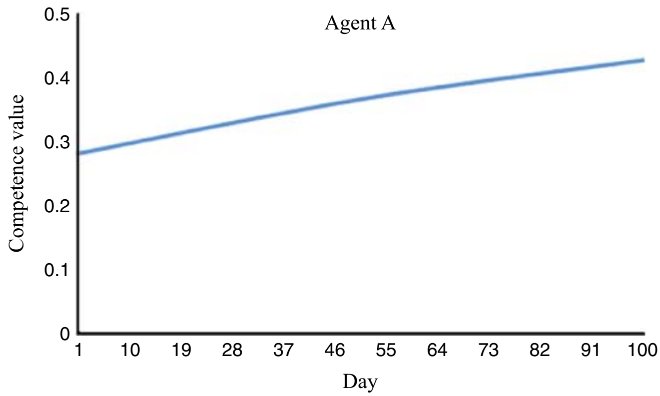

Figure 1.
The simulated results for the variations in the competency value of agent A

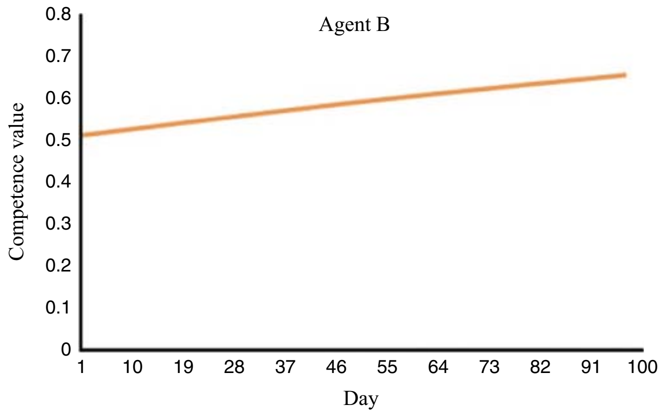

Figure 2.
The simulated results for the variations in the competency value of agent B

A and B has increased from the initial values of 0.28 and 0.52 to 0.426 and 0.667, respectively. The reason is that the knowledge and experience of the agent C who has a higher value of competence is transferred to agents A and B.

However, the competence value of agent C has been slightly decreased from the initial value of 0.86 to 0.779 (Figure 3). The reason is that the initial competency of agent C is greater than the other agents (Table IV). The competence value of agent C is consequently decreased over time due to the effect of forgetting factor.

A sensitivity analysis was also conducted to show how the learning behavior of different agents is affected by various influencing factors including forgetting factor and social ability to teach.

Figures 4-6 represent the variations in the competence value of agents A, B and C against different values of forgetting factor. As the value of forgetting factor is increased, the competence value is more decreased with a higher slope (Figures 4-6).

As an example, Figure 4 shows how the competence value of agent A is increased throughout the project execution depending on the value of forgetting factor. As the value of forgetting factor is increased from 0.003 to 0.007 for agent A, the competence value at the project finish date is decreased from 0.426 to 0.373.

The social ability to teach is another important factor affecting the learning behavior of different workers. In this section, it is investigated that how the competency value of

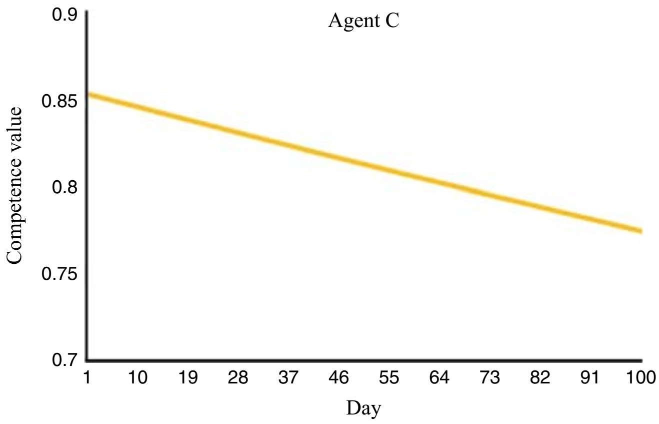

Figure 3. The simulated results for the variations in the competency value of agent C

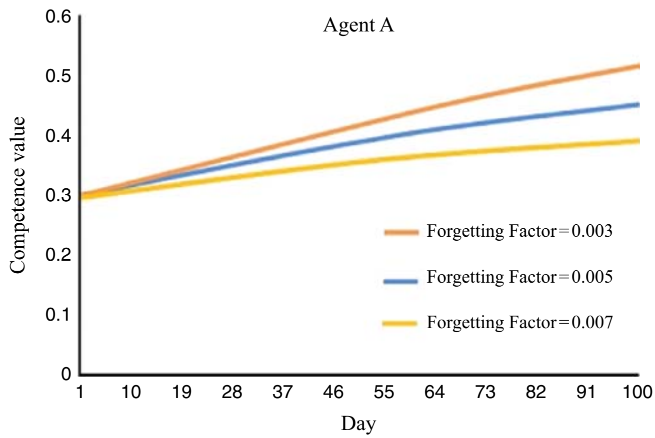

Figure 4. The variations in the competence value of agent A against different values of forgetting factor

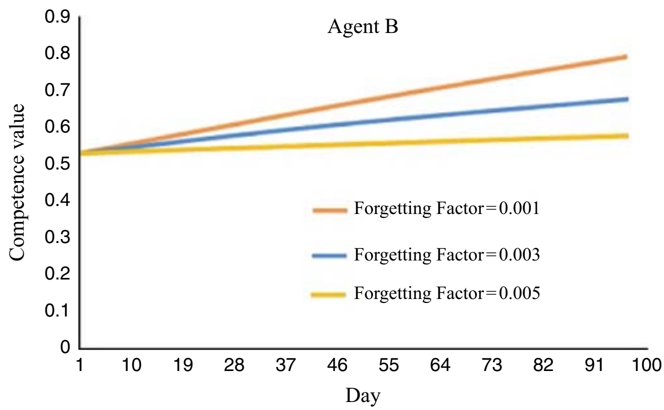

Figure 5. The variations in the competence value of agent B against different values of forgetting factor

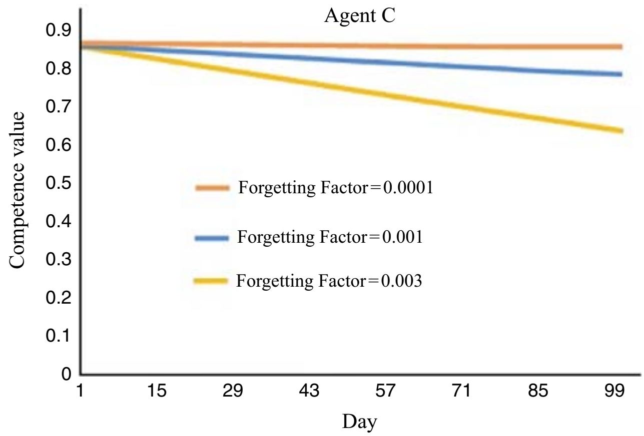

Figure 6.
The variations in the competence value of agent C against different values of forgetting factor

different agents is affected by the social ability of the other agents to teach. Figures 7 and 8 represent the variations in the competence value of agents A and B throughout the project duration against different values of social ability to teach of agent C. The simulated results show that the competency value of agent A is increased from the initial value of 0.28 due to the knowledge transfer from agent C (Figure 7). In the case that the value of social ability to teach is selected as 0.004 for agent C, the competence value of agent A is increased from the initial value of 0.28 to the maximum value of 0.426 at the project finish date. As the social ability to teach is increased from 0.002 to 0.006 for agent C, the final competence value of agent A (in 100 days) is increased from 0.318 to 0.529 (Figure 7).

Similarly, the competency value of agent B is increased from the initial value of 0.52 due to the knowledge transferring from agent C (Figure 8). As the social ability to teach is increased from 0.002 to 0.006 for agent C, the final competence value of agent A (in 100 days) is increased from 0.548 to 0.780 (Figure 8).

Conclusions and remarks

Learning as the process whereby knowledge is created through the transformation of experience is an important way for firms to acquire new knowledge and skills.

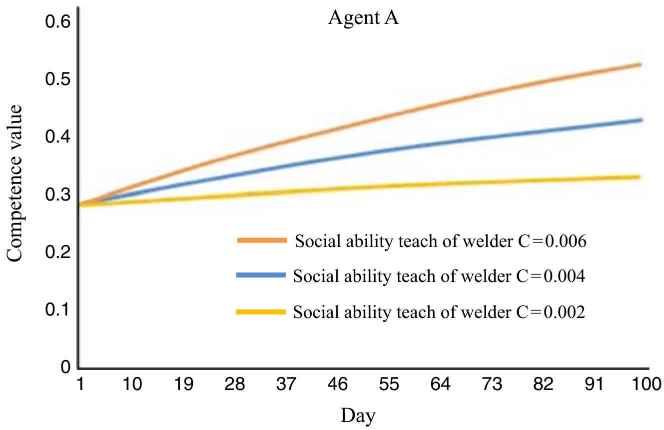

Figure 7.
The variations in the competence value of agent A against different values of social ability to teach of agent C

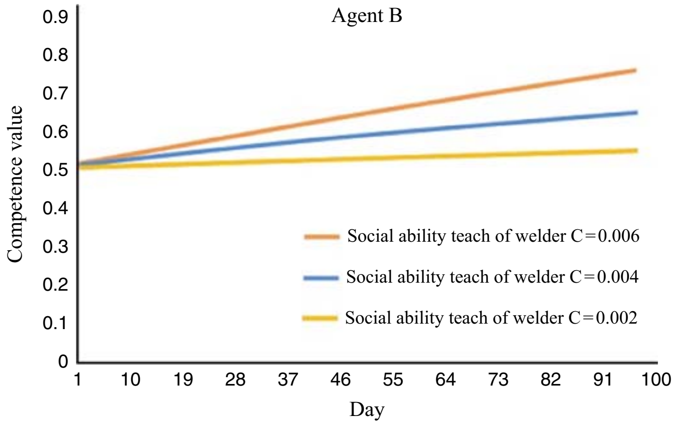

Figure 8.
The variations in the competence value of agent B against different values of social ability to teach of agent C

This research presented an ABM approach to investigate how the competence value of different workers is changed, taking into account their characteristics and interactions.

To evaluate the applicability and performance of the proposed method in modeling the workers' learning behavior, it was implemented in a steel structure project. Using the proposed model, the variation in the competency value of different agents was simulated over time, taking into account the impact of knowledge flow between the agents as well as various influencing factors including social ability to teach and forgetting factor. The learning behavior of different agents was finally predicted considering all the influencing factors.

A sensitivity analysis was then conducted to show how the learning behavior of different agents is affected by various influencing factors. It was concluded that the social ability to teach and the forgetting factor of different workers has a major impact on the workers' learning behavior. The achieved quantitative results confirm the results of previous works that have studied the workers' learning behavior conceptually.

The proposed ABM approach offers a flexible and robust method to predict how the competency value of different agents is changed, taking into account all the influencing factors such as knowledge flow, social ability to teach and forgetting factor. The proposed model also provides the possibility of finding the root causes of a decrease in the competence value of different workers. Therefore, appropriate managerial actions could be taken to enhance the competency level of workers. Although more sample projects are needed to validate the outputs of the model, yet, accounting for the complex interactions between the workers as well as the various factors influencing the learning behavior of workers may provide the decision maker with valuable information.

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