MEASURING LEARNING EFFECTS OF A GAMING-SIMULATION ENVIRONMENT FOR THE DOMAIN OF KNOWLEDGE MANAGEMENT

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ABSTRACT
This study focuses on the learning effects of students involved in learning to solve knowledge management problems. The main question is what students learn from playing KM Quest™, a constructivistic gaming-simulation environment for the domain of knowledge management. Thirty-one students were included in the study. An instrument was developed in order to measure retention of knowledge. The items of this instrument were closely linked with the learning goals of the game. The analysis of difference between pre- and post-test measurements indicates a significant increase in learning results both in terms of acquisition of declarative and procedural knowledge. Future research should indicate to what extent the current test could be adapted in order to measure near/far-transfer of learning, a general aim of constructivistic learning environments and what the added value is of the task model.

KEYWORDS
Constructivism, Gaming-simulation, Knowledge management, Learning in complex domains, Measurement of learning effects, Retention of learning, Transfer of learning

1. INTRODUCTION

Measuring learning to solve problems in a constructivistic learning environment for the domain of knowledge management is not a straightforward business. Solving knowledge management problems concerns solving ill-defined problems for which in essence no univocal outcome exists because there are no strict criteria for the solution. Learning to solve this type of problems is a challenge, let alone measuring it. The research question in this study is concerned with what students learn from playing KM Quest™, a gaming-simulation environment for the domain of knowledge management. This study is part of a larger research project in which the role of metacognition on learning to solve problems is addressed. Before assessing metacognition, first reliable and valid measurements instrument for learning should be developed and baseline learning effects of the environment should be established, that is what this study focuses on. In this section we will first discuss some results of simulations and games with respect to learning in previous studies and subsequently explain our view on problem solving as it takes place in KM Quest™.

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1 This work was partially supported by the European Community under the Information Society Technology (IST) RTD program, Contract No. IST-1999-13078. We are solely responsible for the content of this paper. It does not represent the opinion of the European Community and the European Community is not responsible for any use that might be made of data appearing therein. For more details please see:
1.1 Learning effects of games and simulations

Games and simulations, as a didactic form, fit especially well in the constructivistic paradigm. Basic points of constructivism are that learners actively construct their knowledge by anchoring new information to their existing knowledge base, negotiating meaning through interaction and experience and by using authentic case material with realistic setting and problems (Brown, Collins and Duguid, 1989). Ideally, in games and simulations learners are able to discover and experience the effects of their activities based on realistic case material. However, despite positive expectations about the use of games and simulations in a constructivistic learning context, empirical results concerning learning effects are not convincing. Several studies indicate that results are, at least, sub-optimal of what can be expected.

De Jong & Van Joolingen (1998) published a review study concerning the use of simulations in supporting scientific discovery learning. Their conclusion is that students have problems with discovery learning. Characteristic problems that students encounter fall into the classes hypothesis generation, designing experiments, interpreting data and regulating learning. Moreover, they state that using simulations without additional guidance and support will not lead to optimal learning results. Recent work on inductive discovery learning in simulations by Hulshof (2001), Prins (2003) and Van Rijn (2003) shows that learning results in a simulation for the domain of Optics are similarly weak. Van Rijn however, argues that there is a gap between on the one hand the results found on the knowledge tests that were used, and on the other hand the knowledge actually gained by the students. Basically, learner behavior, both in terms of scientific discovery skills and in terms of the acquisition of domain knowledge is underestimated. Students gain knowledge and use inductive reasoning strategies all right, but because it is unclear for them what to discover and which variables are important to be identified, learners stop before having gained sufficient knowledge. This relates to the notion of the task that students have. It seems that there is a discrepancy between their interpretation of the expected learner behavior and especially task outcomes and those of the experimenter. Concerning games, the effects of acquisition of knowledge and skills are similarly weak. Leemkuil et al. (2000) review a number of studies on the effects of business and non-business games on learning and find that games are effective only if sufficient instructional support is given and clear learning goals are formulated.

Concluding, despite the promises of the constructivistic paradigm, empirical research on learning effects of games and simulations does not straightforward show positive results. It is therefore important to first establish baseline measurement concerning the learning that takes place in KM Quest™.

1.2 Learning to solve problems in KM Quest™

Problem solving can be described as applying knowledge and skills in such a way that an answer is found that was not known before. It is in essence a goal-directed activity. Problem solving in this paper is seen in the paradigm of information processing. Dominant research themes in this field are the development of computational, normative or conceptual models or models that fit in the novice-expert paradigm. These themes overlap. For instance, theories of problem solving in the novice-expert paradigm can have a normative character in terms of prescribing the way an expert solves a particular problem. The view on problem solving that resembles the approach taken in KM Quest™ is described by Mettes and Pilot (1980). They have developed a normative model for the domain of thermodynamics. They propose a systematic approach to problem solving (PAM: programme of actions and methods) for decomposing the problem in subtasks and steps in order to obtain the solution. They propose a task structure that initially consists of the phases orientation, solution and evaluation. The activities in these phases are further decomposed until elementary executable tasks are achieved. Students who have been instructed with this method outperform their peers who have not used this method.

In KM Quest™ a Knowledge Management model (KM model) is introduced (De Hoog et al., 2002). This is a normative model, cyclic in nature that prescribes how to solve knowledge management problems. It consists of four phases, namely FOCUS, ORGANISE, IMPLEMENT and MONITOR. Activities in each of the phases are further decomposed to the level of elementary executable tasks. In the FOCUS phase, players are asked to analyze the current situation of the company, to choose a specific strategy to solve the problem and to set desired knowledge and business indicator related goals. Teams can choose to focus on 1) particular knowledge domains in Coltec (e.g. Marketing, Production or the R&D domain), 2) properties of particular
knowledge processes (e.g. speed of knowledge gaining or effectiveness of knowledge transfer), or 3) the event that takes place. In the ORGANISE phase, types of solutions in terms of types of interventions such as training employees or implementing IT solutions are evaluated for their possible effect on knowledge domains and knowledge processes. In this phase it concerns short-listing relevant interventions based upon their hypothesized effects. For example, interventions that aim at implementing IT solutions could typically influence knowledge retention (databases) or knowledge gaining (Internet) in all domains in Coltec. In the IMPLEMENT phase, interventions are effectuated by means of the voting system. In the final MONITOR phase, teams are asked to reflect upon the changes in the business and knowledge indicators as a result of the interventions that have taken place. Our aim in the present study is to measure learning effects of students playing KM Quest™. The main hypothesis is that students are able to acquire knowledge and skills in KM Quest™.

2. METHODS

2.1 Participants

The participants in this study were 31 students from the Polytechnic Maastricht, 13 women and 18 men. The average age of the students was 22 years (SD = 1.8). The students were enrolled in the study Information Management and Services. They were in their fourth year of their study. All students were novices in the domain of knowledge management, that is, they never have had courses on the subject before. The students had a lot of experience in using e-mail and chat, some experience with shared-writing tools, and a little experience with electronic voting systems. None of the students had ever worked with KM Quest™ before.

2.2 The learning environment

The learning environment KM Quest™ (see Figure 1) was used during this study. The aim of the game is to manage the knowledge household of a fictitious but realistic company called Coltec. The game is divided into a number of quarters. During each quarter, an event takes place. The KM taskforce (a team of three players) is supposed to analyze the events and relevant business and knowledge indicators that reflect the status of Coltec.

![Figure 1. Screenshot of the start page of KM Quest™.](image)
The KM problems introduced to the team in the form of events, can be solved by following the normative KM model. Effects of interventions chosen by the team can be viewed by inspecting various business and knowledge indicators that are part of the Business Model (BM). The BM (De Hoog et al., 2002) simulates the behavior of the Coltec company. It consists of four layers of indicators, namely organisational effectiveness indicators, business process related indicators, knowledge related indicators and knowledge process related indicators. Figure 2 shows the interplay between the indicators of the BM, events (that contain the problem description) and interventions to be chosen by the team.

![Figure 2. General organization of the Business Model of KM Quest™.](image)

In order to support student learning, an instructional envelope is created that encapsulates both the knowledge management and the business model (Leemkuil et al., 2002). Main aim of the instructional envelope is to create support and guidance for the students. It contains instructional support tools that cover: explaining and demonstrating of knowledge and procedures, explicitation and articulation of knowledge, feedback, hints and prompts, monitoring facilities, reflection and debriefing sessions and dictionaries, glossaries and other additional information. For instance, explaining and demonstrating in KM Quest™ is performed through giving expository information to students about the knowledge management model. Also, in the training phase just before playing the game, students are guided through the KM model and can practice.

### 2.3 Instruments

KMQUESTions is developed in order to measure learning. It is an electronic test tool that consists of a number of multiple-choice items that are explicitly based on the learning goals formulated for KM Quest™. These learning goals are formulated in terms of the need to acquire declarative and procedural knowledge in the domain of KM. Declarative knowledge concerns the extent to which factual knowledge is covered, knowing what or which. Knowing that knowledge retention in KM Quest™ means the safeguarding of knowledge from loss from outside is a typical example of declarative knowledge. The learning goals for this part of the test include:

1. Knowledge about performance indicators, such as what business and knowledge indicators exist in the game, how they are organized and what their meaning is.
2. Knowledge about the types of knowledge domains and processes distinguished in the game (e.g. the domains marketing, production and R&D or the knowledge processes gaining of knowledge or transfer of knowledge).
3. Knowledge about the types of interventions one can choose, such as what interventions are, which types exist, what their expected effect is on knowledge and business indicators.

4. Knowledge about how business indicators and knowledge indicators are affected by certain types of events in the game (e.g. when a senior marketing manager leaves the company, properties of the knowledge retention process are affected negatively).

5. Miscellaneous knowledge about why it is important to perform knowledge management activities, what the field stands for, what the definition of knowledge is.

When learning advances, the attention shifts from declarative to procedural knowledge. This is knowledge about how to do things. It is organized in terms of organizational structures such as mental models, cognitive maps or task schemata. These structures serve as mechanisms to increase the organization of a task and anticipate future task requirements. The learning goals covering procedural knowledge are twofold. Firstly, it involves being able to understand and use the KM model on the level of phases and steps. It concerns having knowledge about the task model that prescribes how to solve KM problems and being able to use it. For instance, in the step ‘Where to focus on’ players must be able to decide whether to choose for a knowledge domain, knowledge process or event-based approach based on solid argumentation, depending on the event that is at stake. Secondly, it involves being able to perform activities in KM Quest™, that is, being able to use procedural knowledge in order to complete the task of learning to solve KM problems. For instance, for a particular event, the student should choose the best intervention out of four alternatives.

KMQUESTions consists of two parts, analogous to the two types of learning goals. For each learning goal an even number of questions is developed. The even number of items serves the purpose of creating two parallel versions of the test in order to prevent test-retest effects. Students take the test individually. The final score on the test was calculated by summarizing weighted scores for questions for each of the learning goals. Each learning goal was assigned the same weight. The parallel versions contained 51 items (29 items for declarative and 22 items for procedural knowledge). All questions had to be answered in the light of KM Quest™. The final score (proportion of correctly answered items) on the post-test of KMQUESTions was the grade students received for this part of the institutional course on KM.

2.4 Procedure

In total the students participated in four face-to-face sessions that were evenly spread over four weeks. The first session concerned an introductory lecture (1 hour) about KM Quest™ and a subsequent training session (2 hours) during which students acquired hands-on experience with the learning environment. The introduction and training phase of the game were studied individually during one week. The second session concerned the administration of the pre-test KMQUESTions and the start of the game (2 hours). Students were distributed over teams and entered the playing phase of the game. By the end of week the teams needed to reach at least quarter four in the game. They could play the game at their own pace and location. During the third session (2 hours), students continued playing the game with assistance available. Quarter 7 had to be reached at the end of the week. At the end of the third week students took the post-test KMQUESTions (1 hour). The fourth session (1 hour) concerned a debriefing lecture in which results of the students were announced and an informal evaluation took place.

3. RESULTS

3.1 Reliability of KMQUESTions

The reliability in terms of the internal consistency of the pre- and post-test of KMQUESTions for both parallel versions of the test is calculated by means of Cronbach’s alpha. As it concerns dichotomously scored items (correct answer = 1, incorrect answer = 0) the alpha is equivalent to the Kuder-Richardson 20 (KR20). Because initially reliability coefficients were rather low, several items are deleted. The deleted items were distributed randomly over the learning goals. Table 1 shows the reliability coefficients for KMQUESTions after deletion of items. The generally accepted value of 0.70 can be used as the lower limit for ability test.
However, when the construct being measured is ‘vague’ or ill-defined (such as KM) even lower coefficients can be expected (Kline, 1993). A rule of thumb is that in general when coefficients are higher than 0.5, the ability measured dominates the measurement error or noise in the data. The reliability of the components of KMQUESTions is moderate to sufficient, with one exception; the reliability coefficient of the B version on procedural knowledge during the post-test is low. No explanation was found for this particular outcome.

Table 1. Cronbach’s alpha (KR20 for dichotomous items) coefficients for the items of the subsets declarative and procedural knowledge in both parallel versions of the pre- and post test after deletion of items

<table>
<thead>
<tr>
<th>Version A KMQUESTions</th>
<th>Pre-test</th>
<th>Post-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Declarative (27 items)</td>
<td>0.68</td>
<td>0.65</td>
</tr>
<tr>
<td>Procedural (22 items)</td>
<td>0.58</td>
<td>0.04</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Version B KMQUESTions</th>
<th>Pre-test</th>
<th>Post-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Declarative (27 items)</td>
<td>0.70</td>
<td>0.58</td>
</tr>
<tr>
<td>Procedural (20 items)</td>
<td>0.56</td>
<td>0.65</td>
</tr>
</tbody>
</table>

3.2 Results on KMQUESTions

The score on KMQUESTions indicates the proportion of correct answers. Table 2 shows the means and standard deviations of the scores on KMQUESTions pre- and post-test for group AB and BA and overall. Group AB has first received version A and during the post-test version B, and vice versa for group BA. A T-test is used in order to compare the means on pre- and post-test. This parametric test is used when conditions of normality of test scores can be met or when the total number of cases per condition is 30 ore more. A large increase in test scores exists from pre- to post-test, which is significant ($T(31) = -13.57, p < 0.01$). This suggests that students have acquired knowledge and skills as an effect of playing KM Quest™.

Table 2. Mean and standard deviation of the pre- and post-test parallel versions of KMQUESTions, measured as the proportion of correct answers

<table>
<thead>
<tr>
<th></th>
<th>Pre-test</th>
<th>Post-test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Group AB</td>
<td>0.46</td>
<td>0.13</td>
</tr>
<tr>
<td>Group BA</td>
<td>0.46</td>
<td>0.13</td>
</tr>
<tr>
<td>Total</td>
<td>0.46</td>
<td>0.13</td>
</tr>
</tbody>
</table>

3.3 Increase in declarative and procedural knowledge

The analysis is continued in order to gain specific insight in the increase in declarative and procedural knowledge of KM Quest™ players, the two components of KMQUESTions. In Table 3 the mean and standard deviations and number of participants for both parts of the test are shown.

Table 3. Mean and standard deviation of the declarative and procedural parts in the pre- and post-test of KMQUESTions, measured as the proportion of correct answers

<table>
<thead>
<tr>
<th></th>
<th>Pre-test</th>
<th>Post-test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Declarative</td>
<td>0.44</td>
<td>0.16</td>
</tr>
<tr>
<td>Procedural</td>
<td>0.46</td>
<td>0.14</td>
</tr>
<tr>
<td>Total</td>
<td>0.46</td>
<td>0.13</td>
</tr>
</tbody>
</table>

An increase in declarative knowledge can be observed, as well as an increase in procedural knowledge. The difference between the pre- and post-test measurement for declarative knowledge is significant ($Z(31) = -5.04, p < 0.01$) as well as for procedural knowledge ($Z(31) = -5.77, p < 0.01$) according to a t-test. No differences exist between declarative and procedural knowledge in the pre-test, or between these parts in the post-test. This means that students acquire both declarative and procedural knowledge to the same extent.
4. CONCLUSION

Before turning to the interpretation of the results, a brief critical analysis of the method used in this study is at place. The test KMQUESTions was specifically developed in order to measure the acquisition of declarative and procedural knowledge related to KM Quest™. The reliability of the test is convincingly as the majority of the alpha coefficients are at a sufficient level. For future use of KMQUESTions, however, it is advisable to review the items in detail in order to obtain even more convincing reliability coefficients. This can be achieved by adding additional items to the test or by altering debatable items. Another option is to combine both parallel versions into one test that is distributed both during pre- and post-test. Test-retest effects would probably be ignorable because of the time span in between testing and the large number of items of the test (> 100).

As for the results, to recapitulate, the main aim of this study was to establish learning results of students learning to solve problems in a complex domain. We find a convincing learning effect of students that have played KM Quest™. This is contrary to results of comparable studies in the field of games and simulations. Van Rijn (2003) has argued that learner behavior is often underestimated in simulations, both in terms of knowledge and skill acquisition and in terms of the more domain-independent problem solving skills. As for knowledge and skill acquisition, apparently, KMQUESTions is a valid test for measuring retention of knowledge as it is so closely linked to the learning goals. A possible explanation for the learning effect found is the fact that during the development of KM Quest™, explicit attention was given to the instructional envelope, which aims at supporting and guiding the students in KM Quest™ through a variety of support tools. Another, maybe even more logical hypothesis is that learning has taken place because of the KM model that prescribes how to solve KM problems. Since we have argued that models that consist of decomposed task activities are beneficiary for the learning process, in the next study we will investigate the surplus value of the KM model. Additionally, attention will be reserved in order to review the use of more domain-independent problem solving skills in terms of metacognition.

As for task interpretation, the general mission of students in KM Quest™ was to ‘manage the knowledge household of Coltec as effectively and efficiently as possible’. We are currently analyzing game outcomes and measures in relation to the learning results reported. Game results are for example the end results of teams in the 7th quarter of the game, in terms of weighted organisational effectiveness indicators Profit, Market share and Customer satisfaction index. No relation exists between the weighted average of the organisational effectiveness indicators and the acquisition of declarative and/or procedural knowledge. Other game measures such as the correctness of interventions chosen by the teams or the general status of Coltec with respect to knowledge indicators are currently being analyzed. However, the finding above already suggests that students focus on the knowledge household of Coltec and not so much the business results. This implicates that although KM is a complex domain and KM Quest™ is an information rich environment, students are able to grasp what is expected of them.

In the end the aim of constructivistic learning environments is for students to be able to apply knowledge and skills learned in one setting, to another, thus transfer of knowledge is at stake (Ausubel et al., 1978). Since we now have established learning results in terms of retention, it is now time to focus on transfer. We see two possibilities of measuring the extent to which students are able to transfer their knowledge and skills learned in KM Quest™ to another setting. The first option is geared towards measuring near- and/or low-road transfer. The core of measuring near-transfer is the extent to which the context, in which knowledge and skills are initially learned, differs from the context to which the newly acquired knowledge and skills are applied (cf. Salomon & Perkins, 1989). In essence, features of the contexts should not differ too much in order to permit near-transfer. Low-road transfer takes place when learners have had extensive practice in one domain, and subsequently are able, in a somewhat new context, to (automatically) apply this well-learned behavior. When we apply these ideas to KM Quest™, we aim for developing a test based on a slightly different case than Coltec. The Coltec case material is a prototypical example of a product leadership type of company which aim is to create innovative products (Treacy & Wiersema, 1995). In contrast the HollandSky case (Ediati, 2002) could be used. The latter case is typically a small customer intimacy type of organization. The test for retention of knowledge is based on Coltec, the test for near-transfer should be based on HollandSky. The question is then to what extent students that have played KM Quest™, are able to apply their knowledge and skills to the slightly different HollandSky case, applying the same test design parameters as used in KMQUESTions. With regard to the second option, the extent to which students are able to apply...
their knowledge and skills learned in KM Quest™ to a rather new situation should be measured. This requires a far-/high-road transfer test. The essence of high-road transfer is that students are able to aggregate and abstract knowledge and skills learned in KM Quest™ and subsequently being able to apply and operationalise this in a rather new setting. This requires the use of metacognitive skills that permit students to control and monitor their learning (Mayer, 2002). First, in order to diagnose whether students are capable of far-transfer, the use of (domain-independent) metacognitive skills should be measured for example by means of e.g. protocol analysis. Second, a far-transfer test, for instance in the form of a concept mapping task, should be developed in order to measure far-transfer outcomes.

Future research on KM Quest™ should indicate to what the surplus value of the KM model is with respect to learning to solve KM problems and the extent to which students are able to transfer knowledge and skills learned in KM Quest™ to a different setting. In the end, for learners it is not only important to remember knowledge and skills in one context, moreover, the aim is to help them in learning to use prior domain knowledge and generic problem solving skills when encountering new and unfamiliar problems.

REFERENCES


