Added value of task models and use of metacognitive skills on learning

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Abstract. This study focuses on the effect of a task model on learning to solve problems and the use of metacognitive skills. In two conditions, students played KM Quest, a simulation-gaming environment for the domain of Knowledge Management (KM). In one condition, students had the KM model available that prescribed how to solve KM problems. The other condition provided no such task model. Forty-six students participated in the study. KMQUESTions was used to measure the acquisition of declarative and procedural knowledge. Part of the MSLQ was used in order to measure the self-reported use of metacognitive skills. A significant increase in declarative and procedural knowledge was found. Furthermore, an interaction effect was found between learning *success* and the self-reported use of metacognitive skills. Students who scored low on metacognition, achieved the biggest learning gain. No effect of condition could be reported. The explanation for these results is that KM Quest apparently has succeeded in translating the general principles of the constructivism into concrete teaching examples, and therefore, supports students that are weak in regulating their learning behaviour. Future research should indicate to what extent students in the no-model condition have developed an intuitive model for solving KM problems.

Keywords. Constructivism, Knowledge Management, Metacognition, Problem solving, Task models

1. Introduction

Constructivist learning environments generally advocate the active acquisition of knowledge and skills, collaboration and the use of authentic and realistic case material [1]. Games and simulations fit rather well in this paradigm since learners often can experiment in a highly realistic environment. However, results show that learning is suboptimal in these environments [2]. One of the problems lies in the fact that learners have difficulties in regulating their learning behaviour. In this paper the assumption is that constructivist learning environments, especially games and simulations that concern problem solving, are pre-eminently supportive of learning under the condition that they contain a task model. A task model is a model that prescribes how to solve a particular problem. Mettes and Pilot [3] for example developed a task model for problem solving in the domain of thermodynamics. This Program of Actions and Methods PAM contained all elementary executable activities stemming from the general phases of problem solving,

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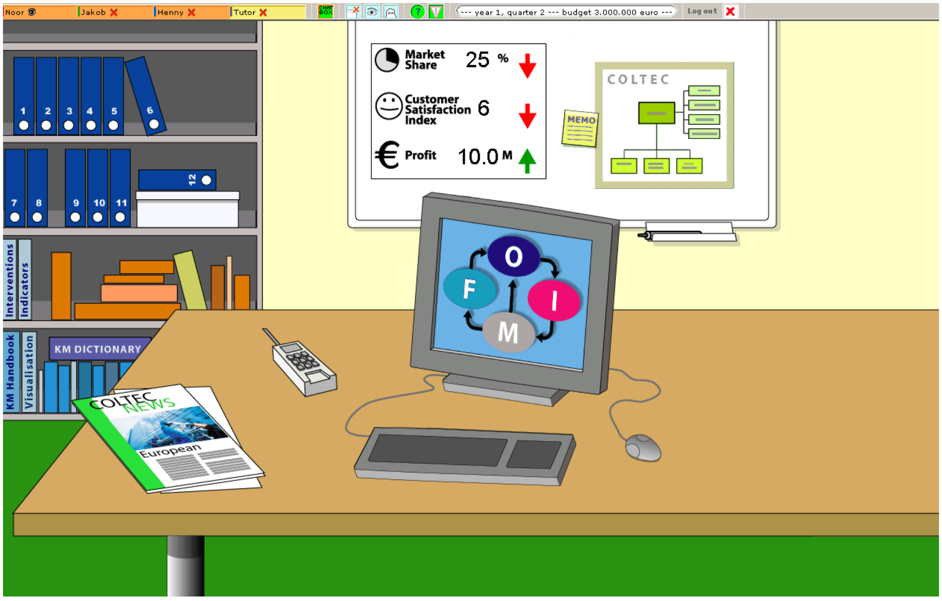

Figure 1. Screenshot of the homepage of KM Quest.

necessary for solving thermodynamics problems. It appeared that students working with this model outperformed students who did not have this model available. From the field of instructional technology and/or psychology the notion of including a task model in a learning environment is seen as a form of instructional support, especially for regulating learning behaviour. Self-regulatory behaviour concerns being able to monitor and control the learning process. It is also called metacognition, that is, the cognition of cognition [4]. In general, the use of metacognitive skills is positively related to learning success [5]. The aim of this paper is to investigate the added value of a task model in a gaming-simulation environment for the domain of Knowledge Management (KM) and the role of metacognitive skills. The learning environment suitable for this research is called KM Quest.

KM Quest[1] is a constructivist learning environment for the domain of KM. In KM Quest teams of three players have to manage the knowledge household of a fictitious company called Coltec. Coltec is a producer of adhesives and coatings and it is headquartered in Delft (The Netherlands). The behaviour of Coltec is simulated by means of a Business Model (BM). This BM contains both business indicators such as 'the number of employees in the R&D department' or 'the number of patents pending' and it contains knowledge related indicators such as 'the level of competence of the marketing employees' or 'the speed of knowledge gaining in the production department'. The overall status of Coltec can be interpreted by reviewing the indicators from the BM.

Each quarter in the game, the team is confronted with a problem in the form of an event. An event is for instance, the leave of a senior marketing manager. It is up to the

[1]KM Quest was developed in the EC project KITS (IST-1999-13078), which consisted of the following partners: University of Twente, The Netherlands; TECNOPOLIS CSATA novus, Italy; Cibit, The Netherlands; EADS, France; ECLO, Belgium and the University of Amsterdam, The Netherlands

team to react upon the event by analysing the problem, setting goals, proposing interventions and checking effects of interventions by reviewing the status of several indicators. For this particular event knowledge retention is at stake since vital knowledge could be at loss and interventions should focus on safeguarding knowledge. The team should propose interventions that counteract this effect. They have a budget for this since interventions cost money. If the team decides to do nothing the decay function of the BM will take over and the status of Coltec will worsen. This reflects part of the competition element essential for games, teams compete against the BM model. The element of chance is represented by having the game fire events randomly. Events differ with respect to whether they represent a threat or an opportunity for Coltec or whether they are interal or external to Coltec. The aim of the team is to manage the knowledge household of Coltec as good as possible.

One of the main ingredients of KM Quest, next to the BM, is the Knowledge Management model (KM model)[6]. This is a normative model, cyclic in nature that prescribes how to solve knowledge management problems. The KM model can be seen as a set of problem solving activities that are instantiated for a specific type of task. In the KM model, the general phases of problem solving, such as for example orientation, execution and evaluation [7] are applied to a monitoring-diagnosis task. Such a task includes analysing an ongoing process and checking whether it occurs according to the expectations, identifying possible discrepancies and if needed, taking action. This process is represented in the phases FOCUS, ORGANISE, IMPLEMENT and MONITOR. The KM model prescribes how to perform this task, because each phase consists of elementary executable activities (steps) relevant for that phase. The model is therefore decomposed at the task-level. In a way, it strongly ressembles the PAM of Mettes and Pilot.

The benefit of the KM model with respect to self- regulatory skills is the following. It is argued [8,9] metacognitive skills of novices in a particular domain are general in nature. Only when they become experts, the domain independent metacognitive skills become domain-specific task schemas. The KM model supports learners in the sense that instantiating these domain independent metacognitive skills into task-related activities is already done for them. It is all laid down in the KM model. Therefore, learners that are presented with the KM model will have less problems instantiating their domain independent metacognitive skills and will learn most. The hypothesis is that the KM model in KM Quest is responsible for the learning success since it represents a compiled model of how to solve KM problems. Furthermore, when no model is present, students that have an adequate framework of metacognitive skills at their disposal will be able to use these skills in order to solve KM problems. They at least have their generic problem solving skills to tackle the new problems. Students that are weak in metacognition, will get lost more easily in the learning environment, since they have no good starting point and therefore achieve suboptimal results.

In order to study the effect of the task model on learning and the use of metacognitive skills, KM Quest will be played in two conditions: one without the task model (no-model condition) versus the standard environment (model condition). Students are assigned to conditions based on randomization. They have equal chance to be assigned to either condition. In a pre-test post-test design, measures of learning and self-reported use of metacognitive skills will be employed. The premises is that learning is taking place, since this was already established in a previous study on KM Quest [10]. Hypothesis 1 covers the main effect of condition: students in the model condition outperform students in the no-model condition with regard to the acquisition of declarative and procedural knowledge. Hypothesis 2 concerns an interaction effect of condition and metacognition. Players in the no-model condition that score high on use of metacognitive skills reach comparable scores on the knowledge tests to players in the model condition. Players in the no-model condition that score low on use of metacognitive skills, perform less on knowledge tests than students in the model condition.

2. Method

2.1. Participants

The results of 46 out of 49 participants are included in the data analysis of this study. Two students dropped out because they had participated in a previous study in this research project. They were assigned to the same team. One student fell ill during the experiment. The average age of the students is 22.7 (SD = 1.6). Thirty students are male, 16 female. No significant differences exist between conditions on the pre-test measurements of declarative and procedural knowledge. This indicates that the samples in both conditions are comparable to each other.

2.2. Learning results

The electronic test tool KMQUESTions is used in order to measure the acquisition of knowledge. It contains multiple choice items (four alternatives) specifically based on the learning goals of KM Quest. The learning goals specifically cover the acquisition of declarative and procedural knowledge. Declarative knowledge acquisition requires the acquisition of factual knowledge in the domain of KM. The learning goals focus on definitions of knowledge processes, meaning of indicators, types of events, types of interventions, effects of interventions and so on. It is tested with for instance, items such as 'What is the definition of knowledge gaining?' or 'Which knowledge domains exist in KM Quest?'. Procedural knowledge acquisition is related to acquiring knowledge about how to solve KM problems. Learning goals involve being able to reflect on the nature of the KM model, understanding the steps of the KM model, being able to apply the steps of the KM model to events and so on. Items are for example 'What do you do in the step "Where to focus on" in the KM model?' or 'Which intervention is best for this particular event?. KMQUESTions was developed in a previous study and appeared to be sufficiently reliable 10]. For the current experiment, KMQUESTions contains 96 items (38 items for declarative and 58 items for procedural knowledge). It is administered before and after the game. Sequence of the items remains the same because there is an optimal ranking in order not to reveal answers. Since there is a mere three weeks between both administrations, possible test-retest effects are considered negligible. The score reflects the proportion of items answered correctly.

2.3. Metacognition

The Motivated Strategies for Learning Questionnaire [11] is a self-report measure that focusses on motivational and learning strategies. The scale Metacognitive self-regulation (12 items) consists of three processes: planning, monitoring and regulation. Planning involves goal setting and task analysis to help activate relevant aspects of prior knowledge that make organizing and comprehending material easier. Monitoring involves tracking one's attention as one reads and self-testing and questioning. Regulation refers to the fine-tuning and continuous adjustment of one's cognitive activities). The scale consists of 12 items that are answered on a six-point scale ranging from 'Strongly disagree' to 'Strongly agree'. The reliability of this scale is sufficient [10,11]. It is administered during the post-test. Students have to keep in mind how one has just played KM Quest. This instrument represent a retrospective self-report measurement of metacognition (Veenman, in press).

2.4. Procedure

The study is carried out in a period of four weeks, prior to any other institutional instruction in KM. In week 1 students start with an introduction into the game. Students of both conditions participate in the introductory lecture. Subsequently, the training session takes place. For each condition, a specific training is developed. The main difference between the two training sessions is the explanation and demonstration of the KM model. After the training, students are administered the pre-test measurements (KMQUESTions). In week 2, students start playing the game during two game sessions that each last over 2 hours. Team members are located in different computer rooms. Communication solely takes place via the chat facilities present in the game. Students do not have access to the game outside the playing sessions. In week 3 a third and last game session takes place in order to reach quarter 7 in the game. The day after, the post-test is scheduled. The post-test consists of the MSLQ and KMQUESTions. In week 4 a debriefing lecture is organised during which students can share their experiences about the game. The instruction to students is to both perform best on the post-test and manage the knowledge household of Coltec as good as possible.

3. Results

3.1. Reliability

The reliability coefficients of different parts of KMQUESTions and the scale metacognition was moderate to sufficient. KR20 (Cronbach's alpha for dichotomous items) coefficients of KMQUESTions were 0.64 for declarative knowledge for both pre- and post-test. For procedural knowledge, this coefficient was 0.78 and 0.52 for pre- and post-test respectively. Cronbach's alpha for the scale metacognition was 0.66.

3.2. Declarative knowledge

In table 1 descriptive statistics for declarative and procedural knowledge are shown.

In order to test the hypotheses, an analysis of variance by means of a General Linear Model with repeated measures was performed. Dependent variables were the pre- and post-test measurements of declarative knowledge. Independent measures were condition and metacognition. Scores on the variable metacognition were divided in two levels based on the median, in order to discriminate between students that scored high and

	$No - model$		$Model$		$Total$	
Declarative	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
$MS-$	0.51 (0.16)	0.63 (0.13)	0.49 (0.08)	0.63 (0.11)	0.51 (0.12)	0.63 (0.12)
$MS+$	0.52 (0.09)	0.64 (0.09)	0.50 (0.12)	0.59 (0.08)	0.51 (0.10)	0.61 (0.09)
$Total$	0.51 (0.13)	0.64 (0.11)	0.50 (0.10)	0.61 (0.10)	0.51 (0.11)	0.62 (0.10)
Procedural	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
$MS-$	0.44 (0.14)	0.58 (0.09)	0.50 (0.12)	0.68 (0.07)	0.47 (0.14)	0.63 (0.09)
$MS+$	0.49 (0.08)	0.56 (0.08)	0.55 (0.14)	0.64 (0.07)	0.52 (0.12)	0.60 (0.08)
$Total$	0.46 (0.12)	0.57 (0.08)	0.53 (0.13)	0.66 (0.07)	0.49 (0.13)	0.62 0.09)
General	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
$MS-$	0.47 (0.11)	0.62 (0.09)	0.50 (0.14)	0.64 (0.10)	0.49 (0.12)	0.63 (0.09)
$MS+$	0.51 (0.14)	0.55 (0.11)	0.56 (0.14)	0.55 (0.08)	0.54 (0.13)	0.65 (0.09)
$Total$	0.49 0.12)	0.59 (0.10)	0.53 (0.14)	0.59 (0.10)	0.51 (0.13)	0.59 (0.10)

Table 1. Mean and standard deviation of the pre- and post-test scores on declarative, procedural and general procedural knowledge measured in proportion of correct answers.

low on this variable. This analysis is repeated for the subsequent analyses. The median is a robust measure for central tendency that is not sensitive for possible outliers.

Concerning within-subject effects, a main effect for learning (comparison pre- and post-test scores) was found (F = 72.13, p < 0.01). Students acquired declarative knowledge as a result of playing KM Quest. No interaction effects were found. Concerning between-subject comparisons, no main effects could be reported. The hypothised interaction effect of condition and metacognition was not found (F = 0.22, p = 0.64). No other interaction effects were found. This indicates that students acquired declarative knowledge regardless of condition and metacognition. Hypothesis 1 and 2 could not be supported.

3.2.1. Procedural knowledge

Concerning within-subject effects, a main effect for learning could be reported (pre- versus post-test scores). Students acquired procedural knowledge as a result of playing KM Quest (F = 38.56, p < 0.01). No interaction effects existed. Concerning between-subject effects, a main effect was found for condition (F = 9.26), p < 0.01). Students in the model condition outperformed students in the no-model condition. This is in line with hypothesis 1. One interaction effect was found, namely between learning *success* and metacognition (F = 4.66, p < 0.05). Students that scored low on metacognition, showed more learning success in relation to students that scored high on metacognition. No interaction effects between condition and metacognition could be reported (F = 0.10, p = 0.75). Hypothesis 2 could not be supported.

The drawback of focussing on procedural knowledge is the fact that 33 items of this test were specific for the KM model. Students in the no-model condition did not have the KM model at their disposal, therefore, it is not fair to include these questions for them. Results indicated that the mean score of students in the no-model condition on KM model specific procedural knowledge was 0.56 (SD = 0.12) and for students in the model condition it was 0.70 (SD = 0.11). This difference was significant (T(46) = -4.14, p < 0.01). Therefore, mean scores on procedural knowledge were calculated again, this time without the KM model specific items. The new measure was called *general* procedural knowledge. In table 1 the mean, standard deviation and number of participants for general procedural knowledge are presented.

Concerning within-subject effect, again a main effect for learning with respect to general procedural knowledge was found (F = 15.69), $p < 0.01$). Students acquired general procedural knowledge as a result of playing KM Quest. An interaction effect of learning success and metacognition existed ($F = 4.55$, $p < 0.05$). Students that scored low on metacognition showed more learning gain than students that scored high on metacognition. Concerning between-subject effects, no main effects could be reported. Hypothesis 1 could not be supported. Students in the model condition, did not outperform students in the no-model condition. Additionally, no interaction between condition and metacognition existed ($F = 0.09$, $p = 0.76$. Hypothesis 2 could not be supported. It appeared that weaker students in terms of self-reported metacognitive skills after task performance, learned most, regardless of condition. Apparently, KM Quest is specifically suited to support students that are less able to monitor and control their learning process.

When conditions differ in the amount of time that is spent on playing KM Quest, it is realistic to assume that there is a relation between time-on-task and learning results. In the no-model condition, students spent on average 3 hours, 52 minutes and 32 seconds, where as students in the model conditoin spent 5 hours, 29 minutes and 22 seconds. This could confound the results. Then, time-on-task should be included as a covariate in the analysis of variance. One of the assumptions for carrying out an analysis of covariance is that a linear relation exists between the dependent variable and the covariate in each condition [12]. This was not the case for this study, therefore, time-on-task did not influence learning results.

3.3. Relation learning results and self-reported use of metacognitive skills

As for the relation between self-reported use of metacognitive skills and learning results, correlation coefficients were calculated to gain insight. The results indicated that hardly any relation was found between learning measures and self-reported use of metacognition. The retrospective measure of metacognition was only related to procedural knowledge measured in the *pre-test* (0.44, $p < 0.01$). This indicated that having sufficient common sense (or prior knowledge) about how to go about in a new task that one has not done before, related to having relevant metacognitive strategies available. This effect disappeared during the post-test measurement of procedural knowledge since then, participants had already developed an idea about the task.

4. Discussion and conclusions

In this study, the objective was to find answers on several hypotheses with the premises that learning would take place. The results reveal that students acquire declarative and procedural knowledge about the domain Knowledge Management, this replicates findings of an earlier study [10]. The first hypothesis can only partly be confirmed. Students in the model-condition outperform students in the no-model condition only with respect to procedural knowledge. Regarding the acquisition of declarative and general procedural knowledge, mean scores in the two conditions do not differ significantly. The second hypothesis, namely about the interaction effect of condition and metacognition, cannot be confirmed. Students in the no-model condition that score high on metacognition, do not exceed students in the same condition that score low on metacognition. However, an interaction effect was found between learning *success* and metacognition. Students that scored low on metacognition, obtained significantly more learning gain than students that scored high on metacognition. Finally the retrospective self-reported use of metacognitive skills did not relate with learning success.

Two conclusions can be drawn from this study. The first one concerns the predictive validity of retrospectively measured self-reported metacognition. Predictive validity is the extent to which a test is capable of predicting behaviour towards a criterion that lies in the future. The better the test can predict variances in a criterion, the higher the criterion -related validity of this test.

In general, in the literature about metacognition one often refers to the fact that it predicts learning success [5]. Students that score high on metacognition, achieve higher learning scores. In this study, the predictive validity of the retrospective self-report measure was low. No significant correlations could be reported of this measure and any post-test result of retention. The conclusion is that this self-report measure of metacognition, is not a good predictor for learning success. So although Pintrich et al. [11] initially set out to support the idea that self-regulated learning promotes learning success, their method, or at least the scale metacognition, does not underpin this relation. It appears that Veenman [13] could be right in assuming that self-report questionnaires lack predictive validity because of the individual reference point that is chosen by the respondent (e.g. comparison with best or poorest classmate or teacher etc), the social desirability of the answers, and the fact that one often does not do, what one says. The aim for the future is to employ a concurrent measure of metacognition, for instance by performing protocol analysis of the communication between team members and to score the frequency of metacognitive contributions. It will also be of interest to compare this measure of metacognition in a social, collaborative context, with individual scores of metacognition.

Secondly, in general the implication of a task model in a learning task was assumed to benefit the learning process because it supports self-regulatory behaviour. In this study, no such result was found. On the contrary, the main finding is that especially weaker students in terms of metacognitive skills appear to benefit from KM Quest, regardless wither a model is present. Their learning gain is highest compared to students that report to be stronger in using metacognitive skills. Apparently, students that are weaker in monitoring and regulating their learning behaviour, benefit most from KM Quest. It is however, not the KM model that they benefit most from, since the addition of this model to the environment does not lead to better learning results. Perhaps the fact that KM Quest is in essence a constructivist learning environment is the reason why weaker students in terms of metacognitive skills achieve more learning success. Maybe for this environment one has successfully translated the theoretical principles underpinning the constructivism into specific didactical and pedagogical teaching strategies that lead to advances self-regulatory behaviour and therefore, better learning, especially for those who need it.

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