The Competence of Learning Companion Agents

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Abstract. One recent approach in developing computer-based learning environments advocates the idea of creating a social context inside the computer. It is claimed that when the learner is engaged into a meaningful dialogue with the software actors his/her learning will benefit. In this paper we concentrate on the collaboration with artificial social actors as peer learners. How ”able” should the learning companion agent be in order to maintain the motivation of the human learner to collaborate? It has been argued that “too strong” or “too weak” companion agents may frustrate the human learner to quit the collaboration altogether. This paper describes an empirical study where the learner is able to work with several artificial learning companions - both strong and weak ones. Our empirical data deals with young school children working on elementary mathematics. On the basis of this study we put forward that a group of heterogeneous companion agents at the learner's disposal will increase his/her motivation to collaborate with the agents. This study also suggests that besides the competence of the learning companion agents it is essential to pay special attention to the personal voice of the companion agents in order to keep the human learner interested.

INTRODUCTION

Collaboration is rather unanimously considered as one of the most important qualities of meaningful and effective learning (see e.g. Jonassen, 1995; DeCorte, 1993) and it is often suggested that computer-support for learning should include also supports for collaborative action. However, there is no consensus of the ingredients of good collaborative situations (see e.g. Dillenbourg et al., 1995; Hoppe, 1995) and, indeed, there are mixed results available from empirical evaluations of collaborative learning situations, with or without computers. In this paper we will provide more empirical data concerning a special collaborative situation, namely that with a human learner working with several artificial co-learners.

Intelligent software agent technology has been suggested as a promising approach to extend intelligent tutoring systems in such a way that the need for social context for learning can be fulfilled (Kearsley, 1993). Intelligent agents in educational applications can have many roles (Hietala & Niemirepo, 1996a). They can be smart tool-like agents searching digital libraries, autonomous co-learners or teaching agents. In our opinion the most essential feature of the intelligent agents is their capability to communicate with humans and other intelligent software agents. The communication ability facilitates e.g. cooperation, initiative and autonomous action taking.

An interesting research question is the following: how capable should the collaborating companion agent be in order to be a useful and meaningful acquaintance for the human learner. On the one hand, should we construct a system that does not know more than the learner but learns by interacting with him/her (Dillenbourg & Self, 1992; 1996). In this approach the question of relevant and sufficient interaction vocabulary is of utmost importance. On the other hand, should the companion agent be an expert who is always able to solve the problem and the

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learner be more like an apprentice? Or should there be many simulated companion agents, each ready to serve when the learner is near their level of competence?

In this paper we want to address the question about the optimal quantity and quality of the companion's competence in the subject matter. We want to explore the factors influencing the collaboration between a human learner and machine companions. Our hypothesis is that when working with several heterogeneous companions the "social effect" will bring out benefits not reported before. The EduAgents framework (Hietala & Niemirepo, 1996b) provides a platform for experimental testing of the above hypothesis.

RELATED WORK

Chan (1995) provides an excellent overview of learning environments involving multiple agents, either working at the same computer or across connected machines. Our interest here lies in computer simulated agents and in the different roles these agents can take via different protocols of learning activity. Chan (1995) summarizes this as follows: if an agent has some expertise of a domain then the agent can act as a teacher or as a student. In the first alternative we have the well-known *intelligent tutoring* paradigm, where the computer agent is assumed to know all the answers and be able to lead the human student to the right path in problem-solving. However, if the computer agent does *not always know* the right answers, Chan (1995) presents three possibilities for learning activities: "computer as a co-learner" (Dillenbourg & Self 1992), "learning companion systems" (Chan & Baskin 1988) and "learning by teaching" (Chan & Baskin 1988; Palthepu et al. 1991). First of all, the computer can act as a co-learner with a roughly equal knowledge level as the human learner and together with him work towards the solution. No teacher is present in this scenario so that the goal is that both learners support and learn of each other. On the other hand, if this dyad is augmented with a teacher agent now both the human learner and the learning companion agent will learn under the guidance of the teacher agent. This means e.g. that both learners can solve in parallel the problems posed by the teacher agent and then compare and discuss their respective solution suggestions. This way both learners can also benefit from the comments of the teacher agent as both of them see these comments. Finally, the third scenario implies that the computerized companion agent starts with a lower level of knowledge than the human learner and the human learner learns how to learn by teaching the learning companion by giving examples or providing information.

In our opinion these new roles for the computer in the learning environments outlined above are very fruitful alternatives to the traditional intelligent tutoring paradigm. They have spawned and inspired much interesting work. Concerning the difficult problem of how to motivate the human learner to work with the agent system, we can e.g. mention the research by Aimeaur et al. (1997) and Uresti (1998). The former advocates the learning companion to possess pedagogical knowledge and to sometimes deliberately disturb the human learner - this "learning by disturbing" strategy aims at making the student to confront his/her weaknesses. Uresti (1998) suggests combining the achievement score of the human student to the score of the learning companion he/she has taught. This is assumed to encourage the human learner to work harder with the companion agent. The issues related to the motivation of the human learner working with artificial agents are considered also in this paper, but from another viewpoint.

For example, in the basic scenarios above there exists only one computerized co-learner, companion or one companion together with one teacher agent. In our opinion, an interesting addition here would be if there would exist *several agents of different kind*, that is, both multiple teaching agents or multiple learning companions would be available for the human learner to collaborate with. The former possibility was discussed in Hietala and Niemirepo (1998), the latter is considered in this paper.

PROBLEMS IN COLLABORATION WITH AGENT CO-LEARNERS

It is well known (Dillenbourg & Self, 1996; Chan et al. 1995) that it is difficult to adjust the level of the machine agents to carry on discussion with the human learner. The agent must not be too anxious - interrupting and demanding feedback all the time, nor is it appropriate that the agent adapts too slowly to the working pace of the learner and gives too many erroneous answers. Let us consider the relationship between the agent and the learner a little bit closer.

To explain the situation for a fruitful collaboration Dillenbourg (1995) suggests a metaphor where two interactive problem solvers - two separate societies of agents - are seen as a single society of agents. The purpose of the interaction is to activate the processes (agents) in the human learner to carry out the processes performed first by the machine agent. Both of the learners have the same resources: at the beginning of the interaction the processes needed to solve the task are performed by the machine agent and later on by the human learner. The duty of the machine agent is to support the learner to activate his/her processes by progressively decreasing its support until the learner is able to solve the task alone. The question remains: how should the machine agent perform in order to get the learner to try to work more individually? Should the agent slowly decrease its level of competence? Perhaps there is something in the learner's side that should be taken into consideration: his/her expectation of the collaboration.

When describing the collaboration in the People Power environment Dillenbourg (1995) states "What one can expect from our partner partially determines one's motivation to collaborate with him. ... Initially, the subjects who collaborated with the machine did not always accept that the computer was ignorant." We can illustrate this importance of the learner's expectation of the companion's competence as follows (see Figure 1). By competence we mean abilities in knowledge, problem-solving and explanation.

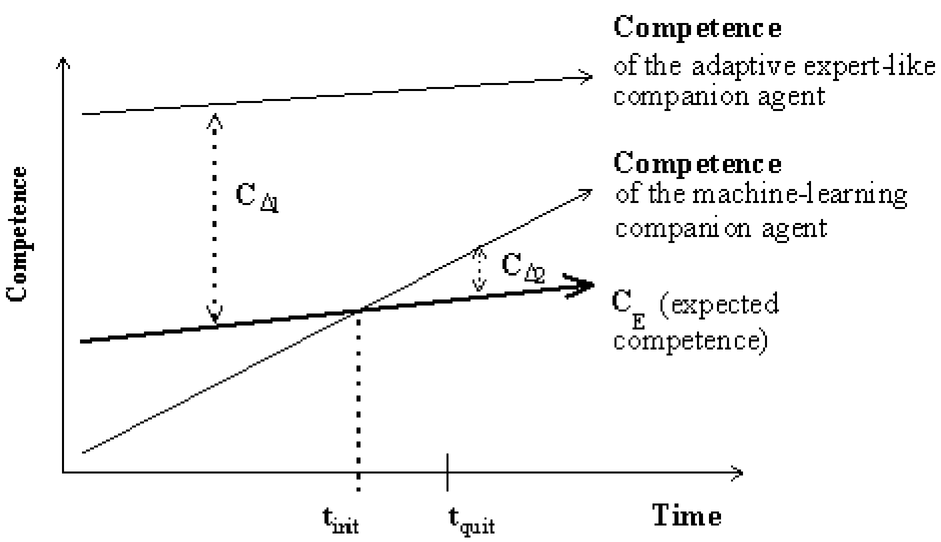


Figure 1. Learner's expectation of the companion's competence

There are four issues related to the learner's expectation of the companion's competence (C_E). **First**, what should the machine-learning companion's competence be at the beginning? Typically there is an initiation phase when a slowly learning companion agent adjusts its knowledge to C_E. Unfortunately, the learner's motivation to collaborate often decreases due to slowness and incorrect answer suggestions before the agent reaches the expected level (t_{init}). **Second**, if the companion manages to reach the learner's expectation limit before the learner reaches his/her time of quitting (e.g. due to boredom) the collaboration (t_{quit}) there is the question of how much ($C_{\Delta 2}$) can the companion exceed the C_E in order to maintain the learner's motivation to collaborate? This question is different than the **third** question of the competence of the strong expert-like companion: how much better ($C_{\Delta 1}$) can the expert-like companion be in order to keep the relation between it and the human learner collaborative (e.g. the agent not becoming too dictative)? And **fourth**, what factors influence to the learner's expected competence of the companion? In order to be able to answer this last question we should know more about the learner, i.e. something about his/her cognitive capabilities and personal traits.

Instead of providing a system with only one (either weak or strong) companion the learner in our EduAgents system can choose to collaborate with both strong expert-like companions and weak only gradually improving companions. With this framework we try to offer some light on the above mentioned four issues through an empirical study.

THE EXPERIMENTAL SETTING

In this section we describe the experimental setting: the subjects, the procedure and the social agent-based learning environment that was used in our empirical study concerning the roles of the learning companion agents. An overall goal of the empirical study was to evaluate the usefulness of our learning framework, above all the human learner's reactions towards ample opportunities to make selections from a set of multiple teacher and learning companion agents. This paper concentrates on our subjects behaviour when working with and collaborating with the learning companion agents. A more detailed description of the EduAgents environment and the overall goals of the experimental evaluation of our current prototype can be found in Hietala & Niemirepo (1996b). The teacher agents are the focus of a paper by Hietala and Niemirepo (1998).

Agent-based learning environment

In the EduAgents environment the learner solves elementary equation problems with the help of several teaching and learning companion agents. The learner has also several learning tools at his/her disposal, e.g. a computerized textbook and a reflection-playback tool. Our implementation environment is MS-Windows with an object-oriented version of the LPA-WinProlog.

Our prototype incorporates four learning companion agents. Each companion agent has an individual name and appearance in the companion's interface window (Figure 2). Besides the appearance the companion agents possess different skills and manner of speaking. Two of them, one pictured as a boy and one as a girl, have quite a good knowledge in the subject matter area and they do not make mistakes, though their answers are not always optimal. In the following they are called *strong learning companion agents.* Two other companion agents, one boy and one girl, have rather poor knowledge and they often make mistakes in their problem-solving, especially at the beginning. They are called *weak learning companion agents.*

From the technical point of view, both strong and weak companions are made available all the correct operations in each situation. They are also aware of a number of incorrect operations produced by a small set of mal-rules. The agents differ in the way they select their operation from these two operation categories. The strong companions always select from the set of correct operations, while the weak ones more randomly select their next operation. Furthermore, all the operations taken by the human learner during this and previous sessions are related to the current situation and this set is made available for the companion agents. Both companions tend to select operations already taken by the human learner. The weak companions randomize their selections towards the correct operations as the human learner becomes more and more confident with these operations (has applied them correctly). Thus the more the human learner carries out correct operations the more correct operations will also the weak companion select. So this way the weak companion slowly improves its behavior alongside the human learner. We are currently implementing learning companions using more standard AI-type machine learning techniques within the EduAgents framework. However, these techniques were not used in the experiment described in this paper.

The companion agents also differ from each other in their manner of speaking: the strong ones are slightly more "knowing" and commanding ("The answer is x=5 and I know it's right") while the weaker ones are a bit more hesitating ("I suggest x=5 as the answer but I might be wrong"). At any time the learner may change the companion agent. Choosing a companion takes place using a special palette. The locations of the agents in palette are randomized to avoid the possibility of selecting always the same agent at the same location.

The collaboration between the learner and a companion agent can take place in two ways. Through the *Basic Working Interface* the learner can ask the companion to suggest the next step (operation and result), after which he/she can ask the companion's explanation for the suggestion (Figure 2). With the *Collaboration Tool* the learner and the companion agent can have domain-oriented restricted collaboration using a given set of speech acts which structure and enable relevant discussion concerning the domain area (Figure 3). This tool enables reciprocal asking and responsibility sharing between the learner and the companion agent. In reciprocal asking both the learner and the companion agent might ask a suggestion for the operation and furthermore an explanation for the suggestion. Responsibility sharing means that the other learner gives the operation and the other one applies it. Both may also criticize each other's suggestions.

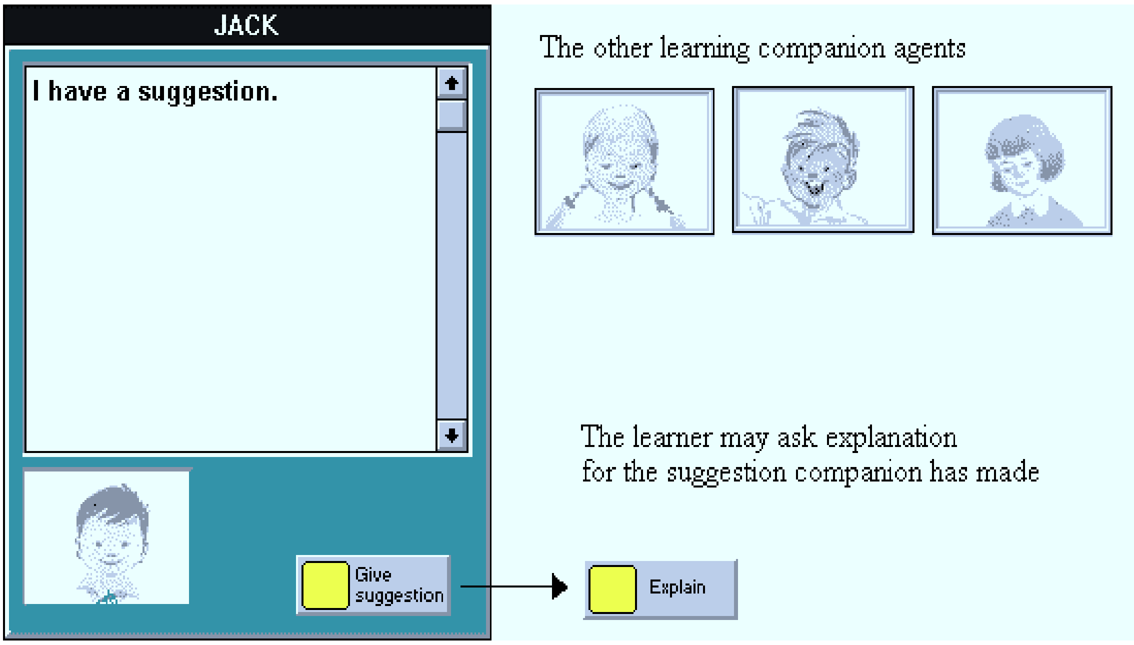


Figure 2. The companion agent's speech window in the Basic Working Interface

The simple sentences produced by the companion agents are composed of pre-defined sentence parts. In this empirical study our goal was to be able to create a rather modest yet rich enough language for the companion agent in order it to be understandable for our young subjects.

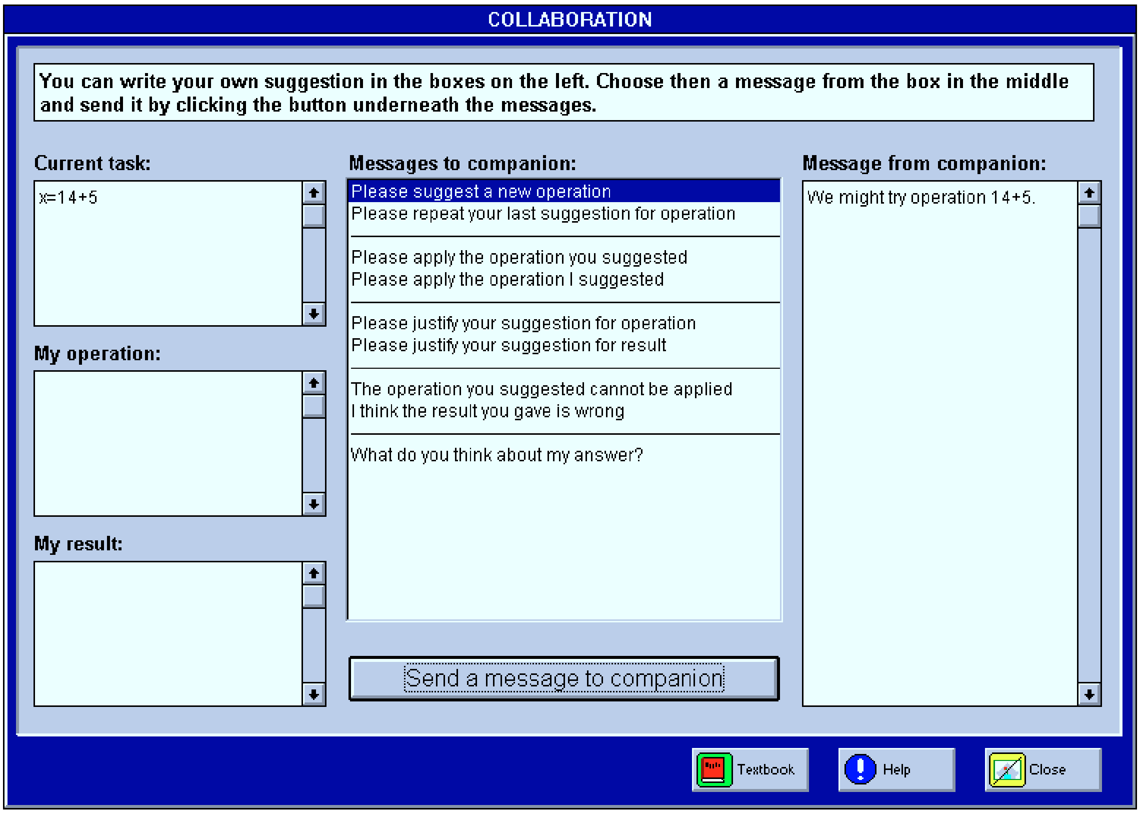


Figure 3. The Collaboration Tool

Subjects

An experimental study was carried out in March-April 1996. The 14 subjects participating in the study are approximately 13 year old pupils from two local schools. They have volunteered by replying to a questionnaire distributed in the schools. The concept of an equation has been introduced to them earlier but they are not familiar with how to solve equations. One educational CD-ROM was randomly drawn as a reward for one among the participants after the experimental study.

Procedure

The experiment took place outside the pupils' school hours and at the Department of the Computer Science on written permission from the pupils' parents. We began our experiment with psychological interviews and tests. The subjects' general learning capability and their personality traits concerning their tendency to turn inward (*introversion*, becoming preoccupied mainly with one's own thoughts) or outward (*extraversion*, deriving gratification mainly from the physical and social environment) was tested. The average IQ of the subjects (101,4 in WISC-R) corresponds to the average scores of this age group. In the following, the subjects are divided into two groups according to their IQ scores: in the *W+* group are the seven subjects with the highest IQ and in the *W-* group are the other seven subjects. The extraversion and introversion personality types (tested with MBTI as a tentative translation to Finnish) divide into the W+ and W- groups quite evenly (see Table 1). During the experimental 3-4 weeks the subjects participated into six 30 minutes sessions. After each session they were interviewed. An achievement test was arranged during the first and sixth sessions.

Table 1. The distribution of the extraversion and introversion subjects into the W+ and W- groups

		WISC-R	
		W+	W-
MBTI	Extraversion	4	5
	Introversion	3	2

One remark concerning the sex of our agents. The inclusion of two female and two male characters (both as teacher as well as learning companion agents) into the environment was decided before recruiting the subjects. Unfortunately, we did not obtain an equal distribution of girl and boy subjects (only two girls volunteered) so we cannot elaborate on this issue further.

In order to help the learner to find the most suitable learning partners for him/herself it was made easy to change both the current teacher and companion agents (a button in a menu that was always available). The subjects were not in any way informed of the characteristics of the teacher and companion agents so they had to find out the "true self" of each agent by working with each different agent.

Research questions

One of our main research questions in this paper concerns the impact of the level of the learning companion agent's skills in the subject matter on the learner's motivation to collaborate (see issues 1-3 in the previous section and Figure 1). It has been suggested that too strong or too weak learning companions have negative impact on the collaboration. But what if the learner has several, both strong and weak learning companions to choose his/her collaboration partners from? Also, are there other factors that influence on the success of the learning companion agents besides the competence of the agents (see issue 4 in the previous section)?

SOME RESULTS CONCERNING THE COLLABORATION BETWEEN THE HUMAN LEARNER AND THE LEARNING COMPANION AGENTS

In this section we report on findings concerning the role of the learning companion agents in the EduAgents environment. Concerning our subjects, we cannot make any assumptions of the distribution of the population and furthermore the sample size was small (14). Therefore the valid test methods should be selected from distribution-free tests. The power of these tests will, unfortunately, be low due to the small number of subjects. In this research we concentrate more on qualitative analysis of the data also because our main purpose is to find out new starting points for future research.

Time spent with the companion agents

How popular were the different kind of learning companion agents? At the beginning (the first three sessions) the subjects spent on an average more time with the weak companion agents than with the strong ones but at the end (the last three sessions) the strong learning companions were clearly more popular (Figure 4). Recall that the subjects had themselves to find out the different "abilities" of each companion agent because agent icon locations in the menu palette were randomized each time applied. So the learners only gradually found "their best partner". During the first three sessions the tasks were quite easy so the learners did not have any particular expectations for the companion agents. However, at the end when most of the learners did not manage to solve the tasks by themselves so they expected some real advantages from the collaboration. On the whole our subjects were satisfied with the companions. To cite the subjects: one comment from the early sessions *"There is most use of the companion when* *one is dealing with a new issue" (Subject 6/session 1),* another comment from the later sessions *"The companion is a real good help. When I have a difficult problem, especially then" (S9/s6).* However, some of them were disappointed when weaker companions made mistakes: *"The companion should not make mistakes in these exercises that seem more difficult, although it would be realistic" (S10/s4).* However, some subjects told in the interviews that making errors was a nice human feature among the weak companion agents and that made them more favorable: *"If the companion does not know all the time, then oneself has also to do some work, just like with real people" (S7/s5).* But on the other hand, some subjects complained that the weak companion agents were a little lazy and irritating because they seemed not even to try to handle the task: *"Pete was the most uncomfortable companion to work with. He was kind of foolish, like 'I don't have the slightest idea, and I don't care a bit to know it', it is not nice to always get a wrong answer" (S1/s6).*

The subjects in the introversion group favored more clearly the strong companion agents at the end than the subjects in the extraversion group (see Figure 4a). This kind of favoring seems to depend on the subject's cognitive capability, too (Figure 4b). The level of companion's skills seems to be more important to the cognitively more capable pupils (W+ group) than to the cognitively less capable pupils (W- group). And not so surprisingly the more socially oriented extravert subjects drew a smaller distinction between the strong and weak companion agents at the end than the more task-oriented introvert subjects.

4a. Extravert and introvert subjects with strong and weak companion agents

4b. W+ and W- subjects with strong and weak companion agents

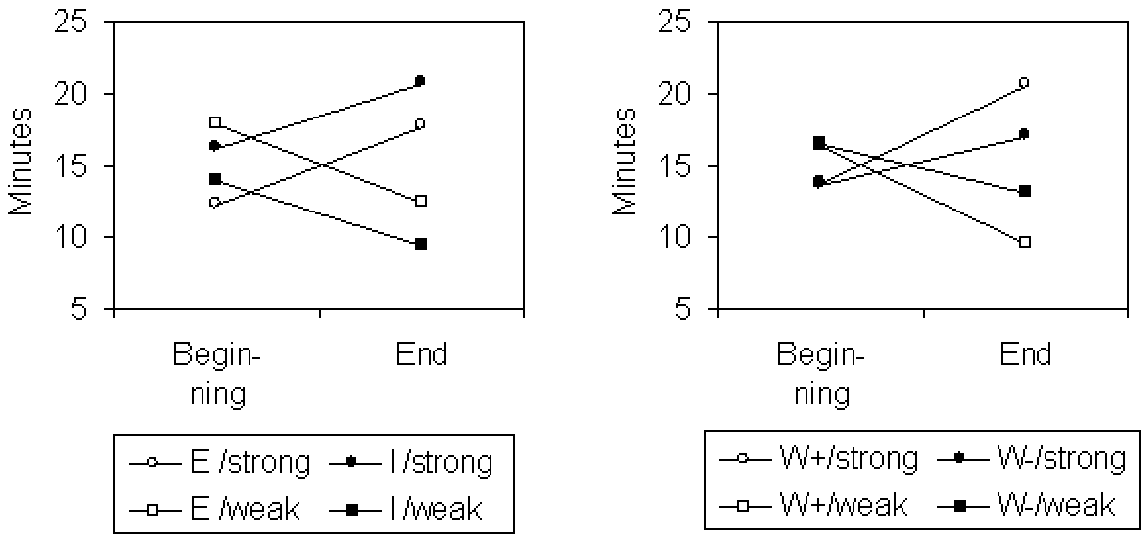


Figure 4. The average time subjects spent with the strong and weak companion agents at the beginning (sessions 1-3) and at the end (sessions 4-6)

A more detailed study of the subjects' preferences of different companions (Figure 5) shows that especially the introverts (W+, I) and (W-, I) found the strong companions and spent at the last sessions more than two thirds of their time with these companions. (Note that because the time in each session was 30 minutes and at all times our subjects had one companion agent selected, time spent with the weak companions can be obtained from formula (30 min - time-with-strong-companions)).

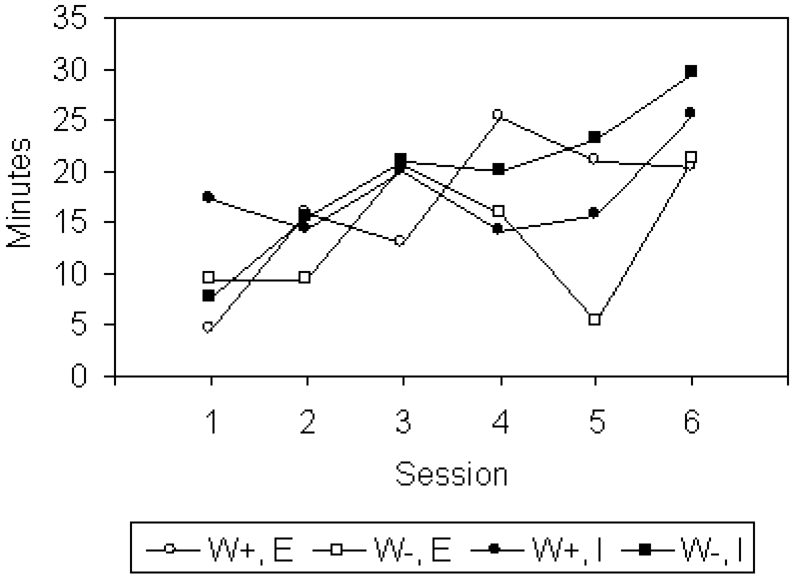


Figure 5. The average time subjects spent with the strong companions in sessions 1-6.

Let us next turn to the number of different learning companions our subjects utilized in the last two sessions (before that session all of our subjects had spent some time with each of the four companions and thus can be said to be familiar with each of them). The average number of companions our subjects worked with in the last two sessions was rather high: 3.25 per session. The success of each of the four companions is rather equal, with strong girl companion the most popular (see Figure 6). It is interesting to note that the introverts utilized more all the four companions, although they favored the strong companions in total time (cf. Figure 5).

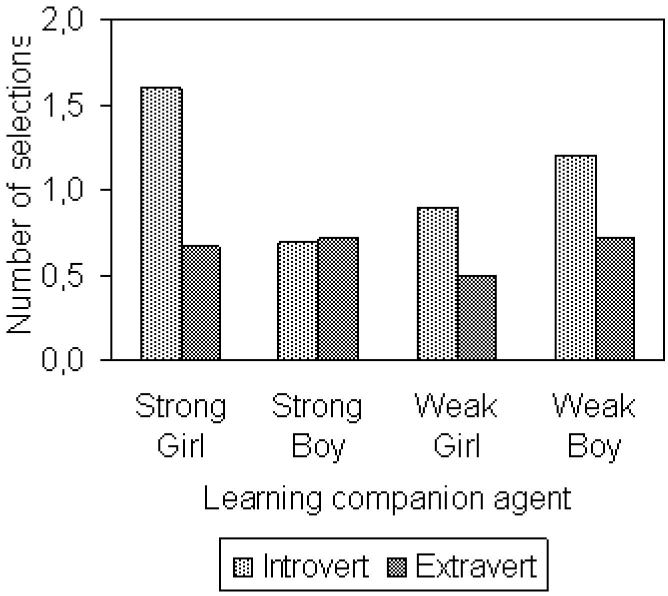


Figure 6. The average number of companion selections of the extraverts and introverts during the last two sessions per session (sessions 5 and 6).

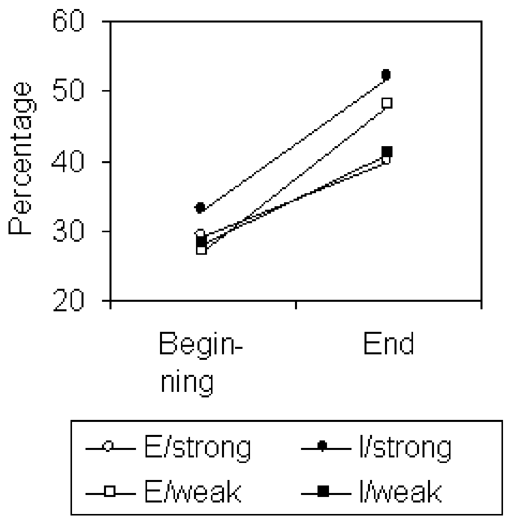
There seems to be a connection to the achievement (which we return later on), namely, the introverts improved most their results in the final achievement test. With their companion utilization pattern (Figure 6) in mind, this suggests that they had found a way of making the best out of the four companions. This can be characterized as follows: work mostly with your favorite learning companion, but also make use of the other three, that is, also with the weak ones.

Accepting suggestions from learning companions

Let us now turn to the behavior of our subjects while working with the learning companions. How willingly did the subjects accept the companion agents' suggestions when using the *Basic Working Interface* (cf. Figure 2) ? On an average the subjects accepted almost an equal number of suggestions from both strong and weak companions. At the end more suggestions were accepted from each type of agents than at the beginning. At the end the tasks were more difficult so the subjects quite simply had a stronger need to ask someone. But when we look at the asking rates in different groups of learners there are differences.

At the end the introvert subjects asked more willingly the strong companion agents' suggestions meanwhile the extravert subjects asked more willingly the weak companion agents' suggestions (see Figure 7a). The same goes for W+ and W- groups: the subjects in the W+ group asked more often the strong companion agents' suggestions and the subjects in the W- group asked more the weak companion agents' suggestions (Figure 7b). It would be understandable if all the subjects asked the strong companions' suggestions because these agents provided good solutions but why did the subjects in the W- group and in extravert group favor the weak companions' suggestions?

7a. The use of companion agents' suggestions among Extravert and Introvert subjects



7b. The use of companion agents' suggestions among W+ and W- subjects

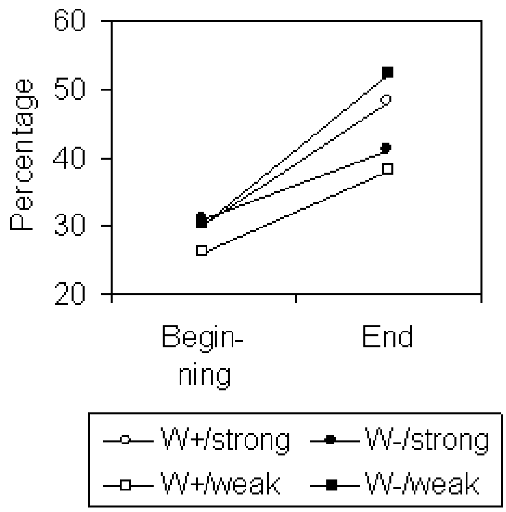


Figure 7. The use of companion agents' suggestions at the beginning (sessions 1-3) and at the end (sessions 4-6) - Basic Working Interface

Let us consider the above mentioned results a little closer. When using the *Basic Working Interface* it turned out that the introvert and the W+ subjects favor the strong companion agents and the extravert and the W- subjects favor the weak companion agents. This tendency seems to come out after the tasks have become too difficult to handle by the learners by themselves alone, that is, only after there is a real need for collaboration. When the tasks are easy to handle alone the subjects seem to be more flexible and patient to interact with all kinds of companions. One reason might be that when the tasks get harder the more capable W+ and the task-oriented introvert subjects favor companions that can help them to quickly advance in the task, while the less capable W- and the socially-oriented extravert subjects favor companions that left them room to make mistakes. In other words, it seems that the weak companion agents' shortage of skills and their hesitating manner to speak made it more comfortable to extravert and W- subjects to fail and show their own ignorance. Another interesting point, these subjects might value strong or weak companion agents on the basis of companion agents' personal voice. Recall that there were differences in the manner of speaking of the companion agents. One subject comments a strong companion: *"That companion was rather rude in the collaboration. He kind of yelled at me: I do not tell you anything because you have not …, he was kind of rude, but it was alright. Maybe he was of that character type" (S11/s6)*.

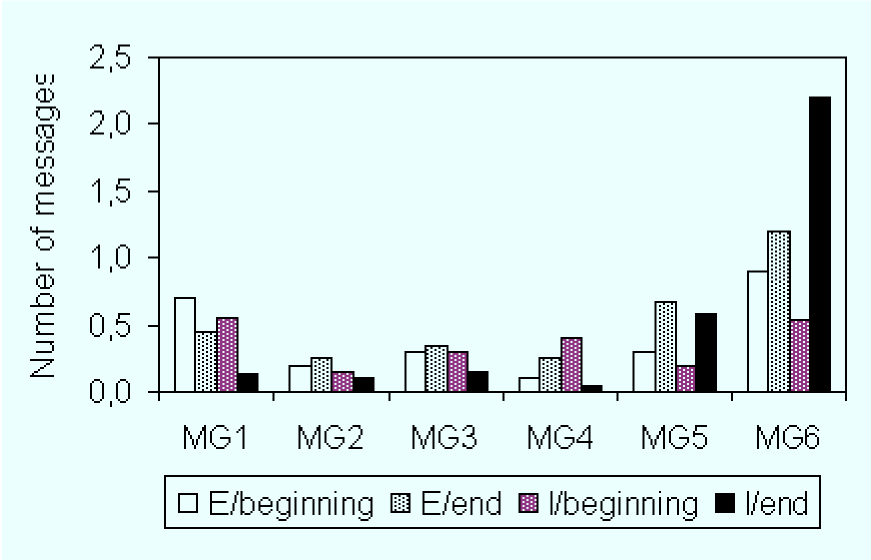
Use of the Collaboration Tool

Another way of collaborating with the learning companions took place through a special tool (*Collaboration Tool*, cf. Figure 3), which was available all the time for the subjects to use. Now we can ask if there were any differences between the learner-groups concerning the conversation with companion agents with the help of the this tool ? At the beginning the most popular messages sent with this tool by the extravert and W- subjects concerned asking the companion agents to suggest a new operation (MG6, see Figure 8). The second most popular message in these learner-groups concerned asking the companion agents' opinion about the learner's own suggestions (MG1). In other words, the extravert and W- subjects want first to know the companion agents' solution and only after that they dared to try themselves. In the introvert and W+ subjects the situation is the opposite: they want first to try themselves and ask the companion agents' opinion about their suggestions and after that they ask the companion agents' suggestion. This was the situation at the beginning when the tasks were quite easy.

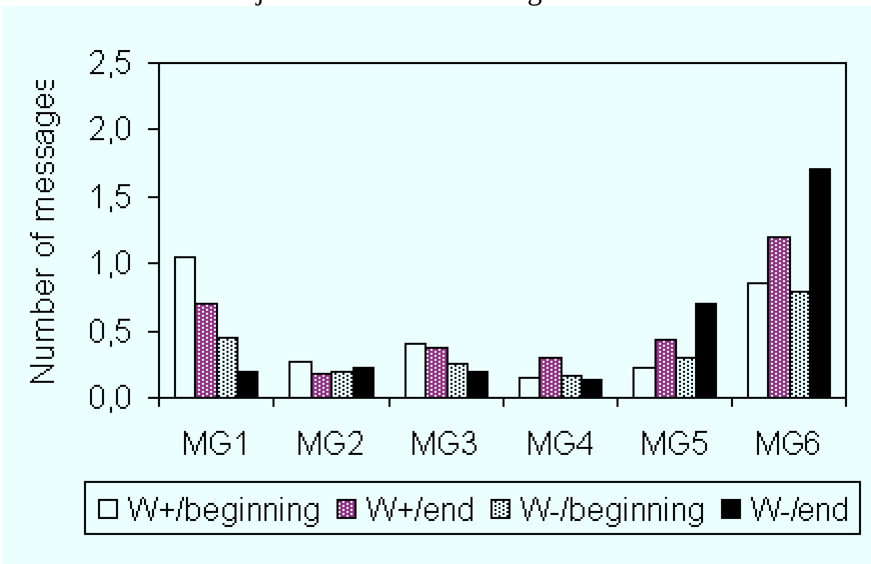
At the end clearly the most popular message almost in each learner-group was to ask the companion agents' to suggest a new operation and after that to apply the operation and give the result. W+ subjects wanted to try themselves too: they asked also the companion agents to suggest a new operation but they wanted to apply themselves the operation given by the companion agents or discovered by themselves. They also wanted to hear the companion agents' opinion about their results. After the companion agents had told their opinion about the learner's suggestion the W+ subjects asked the companion agents to apply the suggestion the companion agents made.

Other kind of messages available with the Collaboration Tool were not used as much as those described above. An achievement-oriented operation MG5 ("Apply an operation you (the learning companion agent) suggested") was the most popular of these other messages.

8a. Extraverts and Introverts: number of messages sent with the collaboration tool



8b. W+ and W- subjects: number of messages sent with the collaboration tool



MG1: what do you think about my answer?
MG2: operation you suggested cannot be applied / I think the result you gave is wrong
MG3: justify your suggestion for operation / justify your suggestion for result
MG4: apply the suggestion I suggested
MG5: apply the operation you suggested
MG6: suggest a new operation / repeat your last suggestion for the operation

Figure 8. The average number of messages in each session sent to the companions with the Collaboration Tool

Student achievement

An achievement test was arranged at the beginning of the first session and at the end of the last (sixth) session. It was a paper-and-pencil test where the students were requested to provide (only) answers to equation problems. No solution process descriptions were required.

Before participating into our experiment students had not received any instruction on how to solve equations step-by-step, but naturally they were able to figure out answers to simpler ones on their own. Moreover, equations do pop up in several situations in their earlier mathematics curriculum (they were all 7th graders). However, the more formal treatment of the equations (similar to that they were faced with the sessions with the EduAgents system) was scheduled to take place during their following school semester.

We did not expect major improvements in the achievement tests due to several reasons. First, six half an hour sessions of problem-solving with a computer program is not, at least in our opinion, a very long period. Second, the sessions with the EduAgents system concentrated on the process of equation solving, not to the product of equation solving - the right answer. The steps in this process were new to the students and were not easily transferred to paper-and-pencil tests where the system was not available. In fact, this seemed to bother and slow down some of our students in the final test because they tried to work similarly as with EduAgents but now on their own with paper and pencil. Of course, the final achievement test being their first occasion to try this out without any scaffolding did not always turn right. Finally, the final achievement test took place after half an hour of work with the system (the sixth session) and almost similar time of interview. So after a tiring session of one hour the students were still requested to answer to the test questions. For some of our subjects this seemed to make heavy demands on their concentration.

As an entire group, our subjects improved their equation problem-solving slightly from the initial achievement test. Both the number of equations correctly solved and the scores weighted by the difficulty of the equations slightly increased. Also the correct solutions were found faster than in the pretest. The greatest improvement took place in the group of introverts.

With reference to Figures 5 and 6, we can say that the improvement correlated with those subjects who had learned to utilize all the four companions, although preferred at the end the strong ones. The introverts who improved most their achievement, appear to have found a way of utilizing the group of companions in a fashion that benefited their learning. This involved not only finding a favorite one (which was a strong companion) but also to collaborate with the other ones, including the weak ones. These initial findings seem to speak in favor of having a group of companions instead of only one.

Summary

We can now try to offer some light on the issues mentioned in the section “Problems in collaboration with agent co-learners”. We begin with the issues concerning the effect of the companions’ competence. When the problems to be solved (exercises) were easy, the collaboration was rather social and many-sided with both types of companions. But after the tasks got harder it seems that the learner can not resist the temptation to ask right away someone. The extraverts and W- subjects preferred to ask the weak companions while the introverts and W+ subjects preferred the strong companions (**first issue**). When working with the *Collaboration Tool* only the W+ subjects who possessed better cognitive capabilities to process new information maintained the tendency to try themselves as well. The extraverts and the W- group seemed to resort to the collaboration with the weak agents even if the competence of the weak companions almost reached the expert-like companions’ competence at the end (**second and fourth issue**). The reason for this choice is perhaps that these subjects felt that their own personal traits and abilities did not conflict with the originally weak and hesitating learning companion. This result also indicates that the competence of the companion is not the only factor that influence to the learner’s motivation to collaborate (**fourth issue**). It seems that when the exercises became more difficult the introverts and the W+ group placed more emphasis on getting the work done. This leads them to resort to the strong learning companions and utilize them as intelligent helpers who give the next solution step in difficult situations (**third and fourth issue**).

CONCLUSIONS AND SUGGESTIONS FOR FUTURE RESEARCH

Our data suggest that there are other ingredients in the human learner / computer agent match-making than just the problem-solving capabilities of the computerized agent. In our experiment, the personality of the agent comprised - besides its capabilities in solving problems - of a name, a picture, and its manner of speech. Our subjects seemed to value the agents according to their human-like traits, not solely as plain tools without a personal voice. This personal voice turned out also as an important feature for companion selection. Making the personal voice of the agent, say, a little hesitating, might encourage a not-so-good and insecure human learner to try out his/her own solution suggestions. Although more research is needed, we believe that these "social" features are important in providing a socially rich-environment for different kinds of learners, as our subjects say: *"The other tools do not replace the companion " (S5/s6)* and *"The Collaboration Tool was the most useful" (S3/s2).*

One human-like feature in some of our agent companions was their ability to make mistakes and to learn slowly, and as we expected: some learners liked it, others didn't. This variability is quite natural. Our approach of providing several agents, some more knowledgeable and some slowly learning ones, turned out to be successful in keeping the learners' interest alive for the collaboration. Some learners even preferred the weaker ones more at the end.

However, we see the empirical studies reported in this paper only as the first steps. The importance of affective factors brought up in this study requires more work to be answered appropriately. In order to dissociate the two factors: the actual level of expertise and the way the agent expresses itself, an empirical study should either provide more combinations of these two factors or concentrate only on the other. One interesting related research area is the area of synthetic autonomous agents (for a survey see e.g. Elliott & Brzezinski 1998) which contains a lot of research results on affective factors.

Finally, we would like to stress that it is rather typical that the collaboration with a learning companion tends to settle down into one communication form, e.g. asking right away for an answer. Thus the social collaboration unfortunately narrows down to be rather one-sided. One possibility to remedy this would be to implement more reactive companion agents, e.g. in the fashion of the "learning-by-disturbing" strategy (Aimeaur et al. 1997). We feel, however, that instead of making companions as "short teacher agents", an attempt to implement some kind of "laziness" or "selfishness" in the agents might be in order, thus leaving room for the learner to explore and come up sometimes also with erroneous solutions. After all, one of the most important features in a learning environment is its ability to engage, tap and sustain the learner's activity in using his/her own problem-solving capabilities. Environments with "real" social collaboration or with "artificial agent-based collaboration" are good candidates for this. In the latter group we hope that the results in this paper provide ingredients to support this overall goal. To conclude we cite one of our subjects, *"Such a companion that knows a lot but answers wrong sometimes would be a good companion. It would be boring if the companion knows the answers all the time." (S12/s5).*

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