COMPUTERIZED SCIENCE PROBLEM SOLVING AND COGNITIVE SUPPORT: EFFECTS ON ACHIEVEMENT OUTCOMES

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ABSTRACT
Four support components were identified (structural, reflective, subject-matter and enrichment) and used to construct four unique cognitive support programs (integrated, strategic, operative and enrichment), based on human teaching (Scardamalia & Bereiter, 1991). The effects of these cognitive support models on achievements were examined and compared to each other and to those of a "base" group. Initially, participants were divided into ability levels by means of a "mathematics and reading comprehension" questionnaire. The instruments used to measure achievement outcomes included three open-ended subject-matter questionnaires, tapping knowledge and understanding of the studied material. These were distributed at different points in time during the research program.

The research findings indicate differential effects of the support programs with differential patterns as a function of time elapsed. The findings are presented and further discussed in the paper.

KEYWORDS
Cognitive support, computerized problem-solving, science problem-solving, achievement outcomes, reflective support, structural support, subject-matter support, lenient measure, stringent measure

INTRODUCTION

Previous research suggests that incorporating computerized learning environments—such as entail inquiry tools, simulation, and/or problem-solving experiences—in science classes, might help the students develop deep understanding of inquiry processes and scientific explanation (Reiser et al., 2001). A number of meta-analysis studies have consistently demonstrated that computer assisted instruction improves students' science achievements and attitudes (Christmann et al., 1997; Fletcherflinn & Gravatt, 1995; Kulik & Kulik, 1991). Huppert, Lomask & Lazarowitz (2002) presented the potential of simulated experiments addressing the problem solving process, enabling students to cope successfully with learning concepts and principles, leading to higher academic achievement.

Yet, there are also examples showing no significant differences between traditional learning and computerized learning (e.g. Morrell, 1992), or only marginally significant results. Consequently, Hokanson & Hooper (2000) pointed out that the expanded use of computers in education continues despite research having failed to accrue definite benefits in learner's performance. Clark (1994) claimed that media are only the vehicles that deliver instruction but that they do not influence student achievement or learning. Fletcherflinn & Gravatt (1995) cautioned that only well designed computerized instruction and materials account for the typical learning benefits. Similarly, Managham & Clement (2000) stated careful attention and research investigation is needed to design and implement effective computerized activities.

In view of that, it might be important and appropriate to investigate the relative effectiveness of different computerized environments on students' science learning outcomes. Chang (2003) compared, for example, teacher-directed with student-controlled CAI formats, and found significantly higher scores for the first format. Soyibo & Hudson (2000) investigated combinations of lecture, discussion and computer assisted instruction. Yet, there have been relatively fewer examples of such research, and the purpose of the current research was to fill this gap.

Since learning within computerized environments poses challenges for most students, mainly for the cognitive complexity of these experiences, it requires coaching and support (Davis & Linn, 2000; Reiser et al., 2001; Swaak, van Joolingen & de Jong, 1998). Walberg's (1990) meta-analysis of some 800 studies on the impacts of instruction factors on the educational achievement of elementary and high school students revealed that the methods that had the greatest effects generally align with the teacher-centred better than with the student-centred education. Hence, the current research examines several support models, which we term *cognitive support programs*. Based upon our search of the scientific literature, we further describe four support components found to be effective in computerized learning environment for science problem solving: structure, reflection, subject-matter, and enrichment. These components served as the building blocks of the support programs offered in this study, in accordance with three human teaching models of & Bereiter (1991).

Thus, the main goals of the current paper are (a) to present the cognitive support programs, (b) to compare the achievement outcomes of the cognitive support programs for computerized science problem solving, and (c) to explore these achievement outcomes as a function of time exposed to the learning environment and to the support programs.

METHOD

The support components

Four support components were designed and used in worksheets, enabling control over the components provided for each student. The first two (structure and reflection), when provided, were the same for all problems.

1. A structural component - providing a general framework that guides the student in problem solving (e.g. De Corte, 2000; Guzdial, 1994). In a scientific domain it might include identifying the goal(s); collecting data; identifying given and missing information; explaining the solution etc.
2. A reflection component - providing a general framework for meta-cognitive skills such as monitoring and control, self-assessment, and self-regulation (e.g. Bielaczyc, Pirolli & Brown, 1995; Davis & Linn, 2000; Scardamalia & Bereiter, 1991). In the current paper the reflection component prompts assessing the solution and explaining difficulties and mistakes.
3. A subject-matter component - addresses domain-specific general guidance and provides prompts for solving problems (see for example, De Corte, 2000; Goodyear, 1992). This component was provided in two modes (see Reif, 1995; Eylon & Reif, 1984): a) a hierarchical subject-matter mode directing attention to both general guidance and specific instructions, and b) a linear subject-matter mode, which directs attention to specific instructions only.
4. An enrichment component – introduced in accordance with the "infusion approach" of Swartz & Parks(1992), including questions that relate the specific problem to other relevant subjects. Specific enrichment questions were presented for each problem, after the original problem has been solved.

The support programs

Based on human teaching models (Scardamalia & Bereiter, 1991), the components above described were used as building blocks to construct four treatment programs (see Table 1): The *integrated support* program constructed on the basis of the "knowledge based" teacher model and included all the components (1+2+3a+4, above). The *strategic support* program was constructed according to the second teacher model, which avoids giving domain specific support, hence included 1, 2 and 4 of the components. The *operative support* program constructed in accordance with the "task model" teacher, who puts emphasis on solving tasks, hence included components 1, 3b and 4. The *enrichment* program included only the enrichment questions (4th component above) without the structural component, thus was non-structural, unlike the other three structural programs. These four support programs were implemented by appropriate worksheets for every problem. Each support program included 42 specific worksheets, to be completed by the students while solving the problems.

Table 1. The Four Support Programs

Integrated support program	**Strategic support program**	**Operative support program**	**Enrichment non structural program**
Structure	Structure	Structure	
Reflection	Reflection		
Subject-matter (hierarchical)		Subject-matter (linear)	
Enrichment questions	Enrichment questions	Enrichment questions	Enrichment questions

In addition to the four treatments described above, a basic treatment was used, which gave no cognitive support at all. Instead, the students were directed to keep notes in their notebooks at their own discretion.

We examined the effect of each support program upon content knowledge (subject-matter achievement). The treatment effects were also compared with one another, and with the basic condition.

The computerized learning environment

The problem-solving computerized environment called Inquire and Solve (Educational Technology Center, Israel) is a micro-world that combines a problem-solving environment with a simulation of laboratory experiments. It consists of 60 qualitative science problems, 42 of which were found to be appropriate for the present research population (seventh grade). Each problem presents a question represented by textual and graphical components (e.g., 'Which vessel contains the greatest amount of air - 1, 2 or 3?'; 'One of the coils in this system is made of copper, another of iron, and a third of aluminum. What is coil no. 2 made of?'; 'In which gas compound - 1 or 2 - do the particles move more quickly?'). The environment enables the students to "perform" the experiment, and "collect" the missing data. The collected data is then to be used rationally to solve the problem posed.

Participants

The research was carried out with 473 junior high school students (231 boys and 242 girls) from 16 classes in 3 schools, similar in size and average level of socioeconomic status. The 16 classes were randomly divided into five subgroups (4 experimental "support program" groups and one "basic" group), with no significant differences in their academic levels ($F(4, 441)=1.20$, $P>.05$ in mathematics; $F(4,441)=1.12$, $P>.05$ in reading comprehension). All five groups were represented in each school. All groups used the same textbook, and worked within the Inquire and Solve computerized environment. Each experimental group was assigned a different support program using the appropriate worksheets. The treatments were conducted for a period of approximately 6 months, as part of the regular class program.

Instruments

Before the beginning of the study, a "mathematics and reading comprehension" questionnaire was administered, to compare the academic level of the participants, and to sort them into three academic levels.

Additionally, two pen and paper open-ended subject-matter, and one multiple choice questionnaires (Q1, Q2, Q3, respectively), tapping knowledge and understanding of the studied material, were distributed at different times during the research period (after one month, three months, and at the end). Q1 and Q2 examined subject matter (with some overlapping), that had been completed by that point in the year, while Q3 included questions from all the studied material. Q1 and Q2 examined explicit knowledge and understanding of already solved problems and their application in new problems appropriate to the computerized environment already covered. Q3 referred both to the computerized problems (implicitly) and the studied material, using multiple-choice items (except for one question), with the additional requirement to explain ten (out of the 20) items.

Two complementary achievement measures were derived from each questionnaire - a lenient (Measure A) and a stringent measure (Measure B) (see for a similar methodology Linn & Songer, 1991). The lenient measure supplies an approximate, surface evaluation of how much the students knows, or the quantity of his/her knowledge (Measure A - *knowledge*), while the stringent reflects a more accurate, deeper assessment of what the student understands (Measure B - *understanding*). For scoring measure A, the student received a score of 1 per item if at least one element is correct, and zero otherwise. In scoring B, the correctness and quality of each answer was assessed, yielding wider scoring ranges.

Three external judges (teachers of the research students) formulated criteria and constructed keys for each measure. After content validity processing (95% agreement among judges), two judges scored each student's responses, with inter-judge reliability coefficients of 0.92, 0.93, and 0.95 for Q1, Q2, and Q3, respectively. Each questionnaire is further described below, with sample questions described.

Q1 contained four open-ended questions, with total of 12 sub-sections. The first question presented a screen of a previously solved problem, with the student being asked to describe the experimental system, and to plan on how to solve it. After submitting their answers to this question, the students received the second question, presented five screens of the same problem, with two "students" arguing that they can already solve the problem. In this question the students were asked to identify the right "student", then solve and explain the problem or suggest what else could be done to solve it. After submitting their answers, the third question was presented, with seven screens. The students were asked, among the 4 sub-questions, to supply and explain the right answer, and to predict the answer in case of different experimental results. The fourth question presented a solving process of a hypothetic problem, with the students being asked to refer to it.

Measure A on this questionnaire includes 18 items, with scores ranging from 0 to 18 (as percentages from the maximum available score), with Cronbach's α=0.88, with a range from 0.44-0.65.

Measure B includes 7 items, on a four-point scale, ranging from 0 (very low understanding – no answer or incorrect answer and no explanation or wrong explanation) to 3 (very high understanding – correct answer and full correct explanation). The range of possible scores (in percentages from the maximum available score), being 0 to 21 with Cronbach's α=0.84, with a range from 0.48-0.71.

Q2: Included three open-ended questions with total of 10 sub-sections, which require thinking and deep understanding of the related subjects. For example, one question was: "Knowing that tin melts at a higher temperature than wax, assume the sticks are attached to the rods by tin instead of wax. Do you expect any effect on the falling sticks? Explain!" This question refers to a computerized problem the students solved, which concerns thermal conductivity of metal rods, with wooden sticks gummed to the rods with wax. The problem solver has to understand that when the wax melts--due to the conducted heat--the stick falls. Due to different thermal conductivity of each rod (because of different metals), the elapsed time for each stick to fall is different. Accordingly, in the above sub-question the students should derive that it would take longer for the sticks to fall since melting tin (at higher temperature) requires a longer heating period; yet the falling order of the sticks is unchanged.

Measure A includes 20 items, with a total score ranging from 0 to 20 (in percentages from the maximum available score), with Cronbach's α=0.91, and a range of 0.39-0.74.

Measure B includes 15 items, 12 of which had a four-point scale while 3 had a three-point scale (0 to 2). The range of possible scores on this measure, therefore is 0 to 42 (in percentages from the maximum available score), with Cronbach's α=0.87, and range 0.37-0.71.

Q3: includes 19 multiple-choice items and one open-ended item (attached with a data page appendix), of which 7 were specially constructed for this research purpose, and the others were adapted from existing tests. In 10 items, explanations of the chosen choice were required as well. An exemplary question is presented: "Which roof best protects the house from the heat? a. A metal roof (e.g. aluminum); b. A cork roof; c. A glass roof. Explain your answer!" In order to answer this question the students should use the heat conductivity scales in the supplied data page, indicating that cork has the lowest heat conductivity (among the three materials), hence it is the best insulator.

Measure A includes 20 items, with scores ranging from 0 to 20 (in percentages from the maximum available score), with Cronbach's α=0.75, and a range from 0.26-0.50.

Measure B includes 10 items with scores ranging from 0 to 9. Hence, the range of possible scores on this measure is 0 to 90 (in percentages from the maximum available score), with Cronbach's α=0.85, and a range from 0.32-0.70.

Procedure

As indicated, the 5 groups used the same textbook and worked within the Inquire and Solve computerized environment once in two weeks. Each experimental group was assigned a different support program by completing the appropriate worksheets. The treatments were conducted for a period of approximately 6 months, as part of the regular class program. The three subject-matter questionnaires were distributed at different times during the research period. Q1 was administered after 2 months, when students had already learned to solve 12 to 17 problems. Q2 was administered 2 months later (when 10 to 16 more problems were solved). Q3 was administered at the end of the research period, when 6 to 9 more problems were solved by each student. A minimum number of problems was compulsory at each stage. Only students who successfully reached this criteria were permitted to go on to the non-compulsory problems.

RESULTS

Brief outline of data analyses

Data analyses included two independent variables -- the cognitive support programs (5 treatments) and the academic levels of the students (3 levels), while the dependent variables for each questionnaire were the two achievement measures – A (knowledge) and B (understanding). A multivariate analysis of variance (MANOVA) was performed for each questionnaire on the two dependent variables, followed by a subsequent ANOVA analysis for each dependent variable, to find any significant difference between the 5 treatment groups. These results were subjected to contrast analyses based on the assumed possible differences, to find out the source of the significant differences between the treatment groups. Contrasting the structural and non-structural groups, the reflection and non-reflection groups, and the structural groups with and without subject-matter component - might shed some light on the effect of structural, reflection and subject-matter components, respectively, on achievement outcomes. An outline of the contrast analyses is presented for simplification in Figure 1 below, and the results which are presented next.

<table>
<tr><td>Integrated support (1)</td><td>Strategic support (2)</td><td>Operative support (3)</td><td>Enrichment support (4)</td><td>Control treatment (5)</td></tr>
<tr><td colspan="3">Structural groups</td><td colspan="2">Non-structural groups</td></tr>
<tr><td colspan="2">Reflection groups</td><td colspan="3">Non-reflection groups</td></tr>
<tr><td>Subject-matter group</td><td></td><td>Subject-matter group</td><td></td><td></td></tr>
</table>

Figure 1.An outline of the contrast analyses

Differential effects of cognitive support programs on achievement outcomes
The results of Measures A and B were subjected to a 5x3 MANOVA analysis (5 treatments x 3 academic levels). The results indicated significant differences among the 5 treatments groups over the two measures at all the three times, as follows: for Q1 – $F(8,828)=10.66$; $P<.001$, for Q2 – $F(8,758)=19.85$; $P<.001$, and for Q3 – $F(8,768)=15.45$; $P<.001$.

The mean scores and standard deviation of Measures A and B for the 5 groups, and one-way analysis of variance (ANOVA) results for each measure are presented in Tables 2 for the Q1, Q2 and Q3 questionnaires. The presented results include only students who had participated in all measures (395 students). As seen in Table 2, significant differences were found among the groups on both measures, mostly in the order of integrated support > (outperformed) strategic support > operative support > enrichment support > control group, except for measure A in Q1 and Q3, with the operative support slightly outperformed the strategic support. Contrast analyses presented next indicate the source of these differences.

Contrast analyses results
Q1: The structural (1,2,3) differed from the non-structural groups (4,5), with significant differences in Measure A (knowledge) ($t=6.21$, $P<.001$) and Measure B (understanding) ($t=5.02$; $P<.001$), implying a dominant effect of the structural component.

Q2: The structural groups (1,2,3) differed from the non-structural groups (4,5), with significant differences in Measure A (knowledge) ($t=7.76$, $P<.001$) and B (understanding) ($t=8.74$; $P<.001$). Additional significant contrasts were found between the integrated (1) and strategic (2) groups in Measure B ($t=2.30$, $P<.05$), and between the integrated (1) and operative (3) groups in Measure A ($t=4.06$, $P<.001$) and B ($t=4.79$; $P<.001$), and between the operative (3) and enrichment (4) groups in Measure A ($t=2.28$, $P<.05$) and B ($t=2.40$; $P<.05$). Summing up - the differentiation among groups is 1,2>3>4,5 for Measure A, and is even greater for Measure B - the stringent measure – with groups 1>2>3>4,5. Besides the continuous effect of the structural component, the dominant effect of the reflection component (included in support programs 1 and 2, but not in 3) might be concluded, with only small effect of the subject-matter component (included in support programs 1 and 3, but not in 2), mainly in its hierarchical mode.

Q3: The structural groups (1,2,3) differed from the non-structural groups (4,5), with significant differences in Measure A ($t=6.17$, $P<.001$) and B ($t=10.06$; $P<.001$). Additional significant contrasts were found only for Measure B between the integrated (1) and the operative (3) groups ($t=2.58$; $P<.01$), and between the enrichment (4) and the control (5) groups ($t=2.93$, $P<.01$). Summing up - the differentiation among groups is 1,2,3>4,5 for Measure A, and is greater for Measure B - with 1,2>3>4>5. This is the only case the enrichment group outperformed the basic group. The great effects of the structural and reflection components on achievement outcomes were apparently deduced from these results.

Table 2. Means, standard deviations and ANOVA results on *measures A and B* for Q1, Q2 and Q3 for the 5 treatment groups

Groups	n	Q1		Q2		Q3	
		Measure A M (*sd*)	Measure B M (*sd*)	Measure A M (*sd*)	Measure B M (*sd*)	Measure A M (*sd*)	Measure B M (*sd*)
Integrated program (1)	80	56.20 (*22.58*)	66.23 (22.96)	59.08 (*26.18*)	50.77 (25.86)	63.66 (*17.58*)	59.20 (*22.37*)
Strategic program (2)	73	52.05 (*26.05*)	61.63 (*25.14*)	52.05 (23.55)	42.47 (22.14)	59.38 (*16.91*)	55.15 (*23.60*)
Operative program (3)	77	53.55 (*27.66*)	59.45 (*21.56*)	43.49 (23.54)	33.70 (21.96)	62.95 (*20.69*)	49.39 (*23.12*)
Enrichment program (4)	91	41.27 (*26.77*)	52.49 (*25.69*)	35.00 (24.43)	25.43 (21.76)	53.54 (*19.23*)	39.86 (*25.37*)
Basic group program (5)	74	35.64 (*24.71*)	48.99 (*24.16*)	29.86 (22.10)	19.30 (19.07)	50.08 (17.25)	29.67 (22.32)
F(4,380)		20.41 ***	13.02 ***	32.94***	42.06***	11.14 ***	31.43 ***

*** P<.001

DISCUSSION

Our predominant finding was that students in the integrated and strategic support groups did better than those in the operative support group. Furthermore, the latter in turn did better than or equaled the achievements of those in the enrichment and control groups. As the support programs and their effects on achievement outcomes were presented, these results are further analyzed and interpreted as a function of time exposed to the support programs, according to the third goal of the paper.

In the first questionnaire, after only a short exposure to the research treatments, there are differences, mostly, between the structural and non-structural groups. The structural groups outperformed the non-structural groups implying early and dominant influence of the structural component, while the other two components were still latent.

After a longer exposure to the research treatments, in the second questionnaire, increased differentiation among the three structural groups was found. On the one hand, there were differences among the reflection groups with the integrated group outperforming the strategic group only in understanding - our stringent measure, but not in Measure A. In terms of the support components we can relate these findings to a moderate increased effect of the subject-matter component which is included only in the integrated group. Yet the difference is limited only to the more stringent and sensitive measure. On the other hand, the two reflection groups outperformed the operative group, in both measures. This seems to imply that the reflection effect increases as a function of elapsed time even more than the subject-matter effect.

After a further exposure to the treatments, at the end of the research period, this differentiation was a little diminished. No differences were found among the reflection groups in both measures, implying that the reflection effect is now so strong that it outweighs the subject-matter effect. Furthermore, by the end of the experiment, the reflection and the operative group differed only in Measure B. This suggests the subject-matter effect on achievements continues to increase, leaving the reflection groups better than the operative group but only in the more stringent and sensitive measure. The strong effect of the reflection component accords with Pirrolli & Recker (1994) suggestion that “reflection on one’s problem solutions is an additional way to improve a declarative understanding of the domain and to improve subsequent skill acquisition” (p. 271). Measures A and B in the current paper assess actually declarative knowledge, which is improved by the reflection component. The subsequent cognitive and meta-cognitive skill acquisition in computerized science problem solving was found as well to have strong effects of the reflection component (see Fund, 1999, 2002).

Additional differences were revealed in Measure B between the enrichment and control groups. This suggests that a long period of exposure to treatment caused the enrichment assignments to have some weak effect, missing till that time. Yet, such difference might be due to the use of similar formulation of test measures (pen and paper questions in both the third questionnaire and enrichment questions).

In conclusion, we see that structural support has a consistent and powerful influence from the beginning of exposure to it, and it is a sine qua non for success. Yet, on its own it is insufficient for maximum benefit, as we see the operative group was lower than the structural groups. The combination of reflection and structural components, common to reflection groups, is needed for superiority in achievements.

The structural component supplies a general framework for solving problems. Following such intervention, the students are able to create effective work patterns. One of the sub-components of this intervention requires students to give a written explanation of the answer (see Fund 2002 for details) This is assumed to support gaining a deeper understanding of the problem, hence improved achievement outcomes. According to explanation-based learning theory, explaining the solution creates links between previous and newly acquired knowledge (Chi, et al., 1994; Bielaczyc, Pirolli & Brown, 1995), thereby improving knowledge construction and understanding, which are further improved by the internal dialogue entailed in committing the explanation process to writing (Scardamalia & Bereiter, 1991).

The reflection component– including predicting an answer, comparing the predicted answer with the correct one, and explaining an incorrectly predicted answer – encourages meta-cognitive processes during problem solving. These processes play a crucial part in knowledge construction (Sternberg, 1990; Zacharia, 2003) and, in turn affect understanding as well as cognitive and meta-cognitive skills and even affective measures (see Fund 1999, 2002, 2003). Elaborated analysis of the reflection sub-components showed that their contribution is due to the meta-cognitive processes they impose on the learner (see Fund, 2002).

A final conclusion refers to the incremental effect of both reflection and subject-matter components. The reflection component works cumulatively over time, probably as the reflective processes become internalized. The subject-matter incremental effect, however, might be explained on the basis of the Adaptive Character of Thought theory of learning and problem solving (ACT-R theory of Anderson, see Anderson, 1993; Anderson et al., 1995), which suggests that declarative knowledge is converted into production rules in the context of problem-solving activity. It is assumed that both declarative and procedural knowledge acquire strength with practice. Since the subject-matter component is involved in these processes, it has a cumulative character, strengthening and increasing as students solve more problems and acquire practice.

REFERENCES

Anderson, J. R. (1993). Rules of the mind. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Anderson, J. R., Corbett, A T., Koedinger, K. R. and Pelletier, R. (1995). Cognitive tutors: lessons learned. The Journal of the Learning Sciences, 4(2), 167-207.

Bielaczyc, K., Pirolli, P. L. and Brown, A. L. (1995). Training in self-explanation and self-regulation strategies: Investigating the effects of knowledge acquisition activities on problem solving. Cognition and Instruction, 13(2), 221 - 252.

Chang, C. Y. (2003). Teaching earth sciences: should we implement teacher-directed or student-controlled CAI in the secondary classroom? International Journal of Science Education, 25(4), 427-438.

Chi, M.T.H., De Leeuw, N., Chiu, M.H. and LaVancher, C. (1994). Eliciting self-explanations improves understanding. Cognitive Science, 18, 439-477.

Christmann, E., Badgett, J. and Lucking, R. (1997) Microcomputer-based computer-assisted instruction within differing subject areas: a statistical deduction. Journal of Educational Computing Research, 16, 281–296.

Clark, R. (1994) Media will never influence learning. Educational Technology Research and Development, 42, 21–29.

Davis, E.A. and Linn, M.C. (2000). Scaffolding students' knowledge integration: Prompts for reflection in KIE. International journal of Science Education, 22(8), 819-837.

De Corte, E. (2000). Marrying theory building and the improvement of school practice: a permanent challenge for instructional psychology. Learning and Instruction, 10, 249-266.

Eylon, B.S. and Reif, F. (1984). Effects of knowledge organization on task performance, Cognition and Instruction, 1(1), 5-44.

Fletcherflinn, C. M. and Gravatt, B. (1995) The efficacy of computer-assisted-instruction (CAI): a meta analysis. Journal of Educational Computing Research, 12, 219–242.

Fund, Z. (1999). Models of written communication as a cognitive support for computerized science problem solving. In P. Brna, M. Baker, & K. Stenning (Eds.), C-LEMMAS, Roles of Communicative Interaction in Learning to Model in Mathematics and Science. Computer Based Learning Unit, University of Leeds.

Fund, Z. (2002). Cognitive support in computerized science problem solving: Eliciting external representation and improving search strategies. In P. Brna, M. Baker, K. Stenning, & A. Tiberghien (Eds.), The Role of Communication in Learning to Model (pp. 127-154). NJ: Lawrence Erlbaum.

Fund, Z. (2003). How to evaluate science problem solving in a computerized learning environment? Construction of an analyzing scheme. In P. C. Constantinou & Z. C. Zacharia (Eds.). Computer Based Learning in Science, conference proceedings 2003, Vol 1 (pp 737-745). University of Cyprus, Nicosia.
Goodyear, P. (1992). The provision of tutorial support for learning with computer-based simulations. In E. De Corte, M. C. Linn, H. Mandl, and L. Verschaffel (Eds.), Computer-based learning environments and problem solving, (pp. 391-409). Springer - Verlag, Berlin: Heidelberg.
Guzdial, M. (1994). Software-realized scaffolding to facilitate programming for science learning. Interactive Learning Environments, 4(1), 1-44.
Hokanson, B. and Hooper, S. (2000) Computers as cognitive media: examining the potential of computers in education. Computers in Human Behaviour, 16, 537–552.
Huppert, J., Lomask S. M. and Lazarowitz R. (2002) Computer simulations in the high school: students' cognitive stages, science process skills and academic achievement in microbiology. International journal of Science Education, 24(8), 803-821.
Kulik, C. L. C. and Kulik, J. A. (1991) Effectiveness of computer-based instruction: an updated analysis. Computers in Human Behaviour, 7, 75–94.
Linn, M.C. and Songer, N.B. (1991). Teaching thermodynamics to middle school students: What are appropriate cognitive demands?. Journal of Research in Science Teaching, 28(10), 885-918.
Managham, J. M. and Clement, J. (2000). High school students' interactions with a relative motion simulation. Journal of Science Education and Technology 9(4), 311-325.
Morrell, D. (1992) The effects of computer assisted instruction on student achievement in high school biology. School Science and Mathematics, 92, 177–181.
Pirolli, P. and Recker, M. (1994), Learning strategies and transfer in the domain of programming. Cognition and Instruction, 12(3), 235 - 275.
Reif, F. (1995). Millikan lecture 1994: Understanding and teaching important scientific thought processes. American Journal of Physics, 63(1), 17 - 32.
Reiser, B. J., Smith, B. K., Tabak, I., Steinmuller, F., Sandoval, W. A. and Leone, A. J. (2001). BGuILE: Strategic and conceptual scaffolds for scientific inquiry in biology classrooms. In S. M. Carver and D. Klahr (Eds.), Cognition and Instruction, twenty-five years of progress (pp. 263-305). NJ: Lawrence Erlbaum.
Scardamalia, M. and Bereiter, C. (1991). Higher levels of agency for children in knowledge building: A challenge for the design of new knowledge media. The Journal of the Learning Sciences, 1(1), 37 - 68.
Sternberg, R. J. (1990). Metaphors of mind: Conceptions of the nature of intelligence. New York: Cambridge University Press.
Soyibo, K. and Hudson, A. (2000). Effects of computer-assisted instruction (CAI) on 11th graders' attitudes to biology and CAI and understanding of reproduction in plants and animals. Research in Science & Technological Education, 18(2), 191-199.
Swaak, J., van Joolingen, W. R. de Jong, T. (1998). Supporting simulation-based learning: The effects of model regression and assignments on definitional and intuitive knowledge. Learning and Instruction, 8(3), 235-252.
Swartz, R. and Parks, S. (1992). Infusion critical and creative thinking into secondary instruction: A lesson design handbook. Pacific Grove, CA: Midwest Publication.
Walberg, H. J. (1990) Productive teaching and instruction: assessing the knowledge base, Phi Delta Kappan, 71, 470–478.
Zacharia, Z. C. (2003). Using interactive simulation to enhance students' explanations regarding physical phenomena. In P. C. Constantinou & Z. C. Zacharia (Eds.), Computer Based Learning in Science, conference proceedings 2003, Vol 1 (pp 471-476). University of Cyprus, Nicosia.

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