COGNITIVE LEARNING OUTCOMES OF AN INSTRUCTIONAL MICROCOMPUTER GAME

Dr. Abdullah Shaban*
Dr. Marv Westrom**

* Scientific School Project, Qatar
** University of British Columbia, Canada

Abstract.

Cognitive learning outcomes (achievement: Concepts, Rules, Procedures) of an instructional microcomputer game called "Mission: Algebra" and the relationship between these outcomes and the intrinsic motivational effects (Challenge, Curiosity, Control, and Fantasy) of the game are examined. There was no difference between achievement and retention scores of students playing the instructional game and those learning through high-intensity worksheet sessions, but boys scored higher than girls on both tests. There was significant interaction between gender and Perceived Creativity on the concept part of the achievement test and all three parts of the retention test. Concept achievement was positively correlated with both Challenge and Control. Rule achievement was positively correlated with both Control and Fantasy. Results indicate that overall motivation can be manipulated sequentially by its factors. Motivation can be instilled and sustained by having factors overlay; appealing first to Curiosity, then to Challenge, and finally to Control.

The way people learn has long been a central issue in psychological research. Gagné (1984) suggested that studying what people learn forms an essential step in understanding how they learn. He identified five categories of learning outcomes one of which involves the intellectual skills of applying Concepts, Rules, and Procedures. In the highly structured classroom, it is especially important for the practitioner to be aware of the kinds of learning that can best be achieved by students in a certain instructional environment.

Motivating environments have formed the focus of attention of various learning theories that agree that motivation initiates and directs behavior, and leads to particular responses that are directed toward achieving a specified goal (Dubin and Okun, 1973). Since it is so central to performance and learning, motivation has been considered basic for making various pedagogical decisions. Yet, it is argued that motivation has not received the attention in educational theory and research that learning has. Spitzer (1996), for example, claimed that "motivation barely gets a mention in most books on learning theory, instructional design, or medial." Thus, there is an apparent need to study the kinds of learning that can be enhanced by particular motivating environments.

However, motivation has been approached in different ways. For example, while Hull explained this concept within a framework of reinforcement, cognitive theorists dealt with it as an internal process where humans set their own goals and make choices about what to do. Furthermore, a distinction between externally administered rewards and punishment and intrinsic, self-administered rewards has been established, augmented by research on the effects of each. Bruner (1960a, 1960b) advocated the integration of intrinsically motivating classroom activities in children's learning episodes by utilizing discovery that can be initiated by intrinsic motives like curiosity and competence.

Educational applications of motivation varied with the varying approaches attached to it. One such application deals with enhancing motivation in the classroom. Lepper and Malone (1987) raised the fundamental question of whether the devices used to enhance intrinsic motivation also further the desired learning. They identified four individual intrinsic motivating factors: Challenge, Curiosity, Control, and Fantasy, and three inter-personal factors: Cooperation, competition and Recognition (Malone and Lepper, 1987). Spitzer (1996), on the other hand, called for building sufficient motivators into one's instructional design to make the underlying learning tasks highly motivating. These motivators include, among others, the contextual factors of challenge, choice, fun, recognition, and social interaction. It is clear then that further study is needed to identify the determinants of intrinsic motivation.

Williams (1980) designed a four-factor Test of Divergent Feeling that forms part of a more comprehensive test (the Creativity Assessment Packet) used to evaluate factors of creativity in children. Four component factors of Perceived Creativity (Complexity, Curiosity, Risk-Taking, and Imagination) are identified in this test. These factors appear to correspond closely to Malone and Lepper's individual intrinsic motivations (Challenge, Curiosity, Control, and Fantasy), thus seem worthy to include in the current study.

Microcomputer games can be used to study phenomena in ways that are difficult to study otherwise. Using such games, intrinsic motivation can be studied in a classroom as well as a laboratory setting that can be manipulated to give a clear indication of any change in intrinsic motivational factors. In earlier studies, change in time in a free-choice period was used as an indicator of change in intrinsic motivation.

In addition, microcomputer games have a wide range of capabilities for instruction and instructional research. While playing such games, student errors can be rapidly diagnosed and corresponding appropriate instructional materials can be generated. For example, a learning episode using microcomputer games can be adjusted to the child's need for concept acquisition or for practicing procedural skills. Facts and rules needed for a certain application can also be readily available. Moreover, such an episode can turn into an enjoyable task for children.

Currently, several research projects focus on creating learning microcomputer game environments in which children are active model builders and programmers rather than passive receivers of information. It is argued that, in such environments, children will be able to learn more complex ideas and advanced concepts as they explore and experiment while they play. For this purpose, special laboratories are being built (Palmer, 2000) where "new research work on how children learn in the digital age will begin immediately" (Heimburger, 1998). Another major concern in these projects is whether instructional microcomputer games can be constructed that are indiscriminating (e.g., between boys and girls, among different racial or socio-economic groups...).

The present study investigates the potential of microcomputer game environments for enhancing cognitive learning and increasing the intrinsic interest in learning. In particular, it examines intrinsic motivational effects and cognitive learning outcomes of engagement with a selected instructional microcomputer game and explores whether this game differentiates in its factors between boys and girls or among children with different levels of Perceived Creativity. It's meant to subscribe to a line of convergent perspectives of research on motivation and learning and complement an earlier research study by the authors on the motivational effects of two games that were used in both studies. In the earlier study, it was concluded that, by manipulating factors of intrinsic motivation, effective instructional tools can be constructed where learning itself is the motivation and where learning is fun (Westrom and Shaban, 1992).

Method

The study utilizes an experimental research design approach with an experimental group and a control one. It examines achievement and retention factors, as well as intinsic motivational factors and factors of Perceived Creativity. Specifically, the study examines:

1 - Differences in achievement and retention between the experimental and control groups, between boys and girls, and among students with different levels of Perceived Creativity.

2 - Correlation of achievement (Concepts, Rules, and Procedures) to intrinsic motivation (Challenge, Curiosity, Control, and Fantasy).

Subjects in the experimental group play an instructional microcomputer game called "Mission: Algebra" and a non-instructional game called "Lode Runner". Subjects in the control group play the non-instructional game and use worksheets to practice the mathematical contents of the instructional game. The two games as well as the worksheets are described next.

The Games

Lode-Runner is an arcade-style, real-style, real-time action game in which the hero infiltrates different treasure rooms, runs, jumps, climbs ladders, and recovers treasures while evading or trapping deadly guards. To infiltrate a treasure room, the hero must collect all treasure chests available there before he can move to the next room.

Mission: Algebra is an educational game designed to motivate students and give them practice in simplifying algebraic equations and plotting graphs. The player is captain of a space ship who receives a message that a sister ship has been disabled and must be rescued. To do this the player must retrace the path of the lost ship. Clues are given in the form of linear equations, and calculating the path requires the plotting of graph points. Points are won for simplifying an equation, for plotting a graph point, and for making a correct estimation about the next position of the lost ship. Points are lost for each wrong answer or for using a Help facility built into the game (Figure 1).

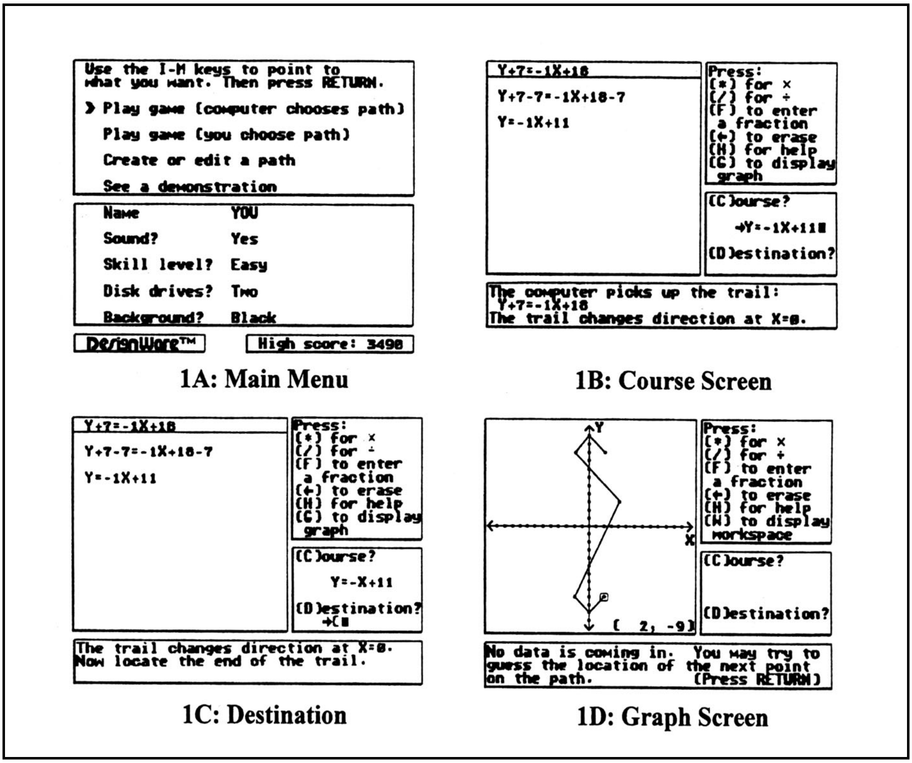

Figure 1. Mission: Algebra

Worksheets

The control group work sessions were intended to provide, as far as possible, an activity that was algebraically equivalent to the Mission: Algebra game, but without the microcomputer game motivation. For this purpose, worksheets were designed in such a way that students simplified linear equations, made estimates and plotted graph points in a way similar to that employed in the game. The worksheets contained exercises chosen at random from Mission: Algebra.

Instruments

Williams' Test of Divergent Feeling was administered to assess students' level of Perceived Creativity. It is a 50-item multiple-choice exercise that yields a total weighted raw score and four sub-scores of Curiosity, Imagination, Complexity and Risk-Taking, all affective in nature. Based on results obtained in a previous research study (Westrom and Shaban, 1992), only total Perceived Creativity scores were used in the present study. These scores were categorized as high, average or low, based on norms obtained by Williams (1980).

Two multiple-choice item tests of intrinsic motivation were designed, one for each of the two games. Each test has a Challenge, a Curiosity, a Control, and a Fantasy part, and uses elements from the game that were matched as being equivalent in context to elements from the other game. Completing a mission in Mission: Algebra was equivalent to exiting from a treasure room in Lode Runner; solving equations was equivalent to overcoming guards; and plotting a point on a graph was equivalent to collecting a treasure chest.

An achievement test of algebra having Concepts, Rules, and Procedures sections was used in the study. The Concepts and Rules parts are multiple-choice item tests, and the Procedures part is a step-by-step solution test. The test utilized algebraic and graph concepts, and rules of transposition and order of operations.

Both the motivation and algebra tests were pilot-tested for reliability using test-retest correlation coefficients. Acceptable estimates of reliability were obtained (Table 1).

Table 1. Reliability Coefficients

	Mission: Algebra	Lode Runner	Concepts	Rules	Procedures
Reliability	r = 0.77	r = 0.94	r = 0.60	r = 0.59	r = 0.83
Coefficient	p = 0.003	p = 0.000	p = 0.027	p = 0.029	p = 0.001

PROCEDURES

Five mathematics classes randomly selected from the tenth grade in a secondary school in British Columbia, Canada, participated in the study. After taking the test of Perceived Creativity, the students were randomly assigned by class and gender to either the experimental or control group. There were 74 girls, half of whom were in the experimental group; and 60 boys, half of whom were in the experimental group. The experimental group played Lode Runner and Mission: Algebra. The control group also played Lode Runner but practiced on the algebraic content of Mission: Algebra using worksheets.

At the time of the experiment, the students were studying a unit of algebra related to the contents of the instructional game. No direct instruction on these contents had been previously given to the students. They were told that the experiment was part of the unit of instruction they were studying and that they will be tested on the Algebraic contents of the game.

Students in the experimental group were asked to sit for five playing sessions in five consecutive days, each session taking one class period. The first session was used to introduce the players to the games and to let them practice playing. In the remaining four sessions, they played the two games alternatively, answering a test of motivation each time (figure 2) The algebra test was administered to these students on the first school day after the last session as a test of achievement and, five weeks later, as a retention test.

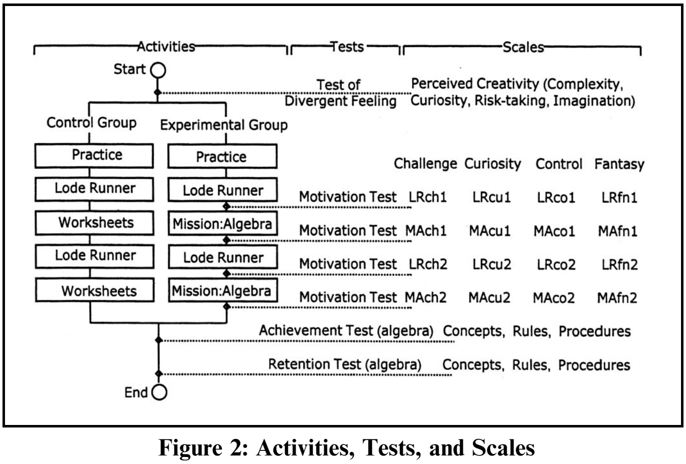

Figure 2: Activities, Tests, and Scales

Similar to the experimental group, students in the control group also attended five sessions. The first session was used to introduce the students to Lode Runner and the worksheets. In the remaining four sessions, they played Lode Runner or engaged in intensive work sessions alternatively. The control group took the same test of Algebra and at the same time that the experimental group did.

While students were solving the problems, the instructor patrolled the aisles marking the problems (right or wrong) and giving immediate feedback. This turned out to be extremely motivating as well. Students were initially told not to expect to be able to complete the worksheets during the class period, but many of them took this as a challenge and most of them did complete the worksheets.

It appeared that these students were working on their algebra at full capacity. Because of the nature of the activity, they answered significantly more algebra questions than the students who played Mission: Algebra. However, instructors found this activity extremely demanding. They felt they could not maintain this level of interaction for longer than two periods at a time.

RESULTS

Multivariate analysis of variance was performed to examine achievement and retention. Univariate analysis of variance was performed whenever a significant F-value was obtained. Pearson correlation coefficients were used to examine the relationship between achievement and intrinsic motivational effects of the instructional game. An asterisk (*) is used to indicate a significant statistic where $p \leqslant 0.05$ was obtained, two asterisks (**) for $p \leqslant 0.01$, and three asterisks (***) for $p \leqslant 0.001$.

Perceived Creativity

The test of Divergent Feeling was administered first, producing scores on Complexity, Curiosity, Risk-Taking, and Imagination. These were summed for a total score of Perceived Creativity that was used in further analyses. A mean of 67 (S.D. 11) was obtained in the current study; it was significantly higher ($z = 2.91$) than the mean of 62 (S.D. 18) obtained by Williams (1980).

Achievement and Retention

Results of the analysis for achievement and retention are reported in Tables 2 and 3. The results of both rests were identical in terms of the significance of their effects except that the two-way interaction between gender and Perceived Creativity is attributed to Concepts only in achievement and to the three parts (Concepts, Rules and Procedures) in retention.

Main Effects: There were no significant differences in achievement or retention scores between the experimental and control groups or among the three Perceived Creativity groups. On both tests, boys scored significantly higher than girls on Concepts and Rules.

Table 2. Analysis of Achievement

Effect	ms	error ms	df	F-value	significance
Treatment			(3,102)	0.33	0.88
Gender			(3,102)	6.58	0.000***
Concepts	115.49	8.53	(1,104)	13.53	0.000***
Rules	112.91	7.20	(1,104)	15.68	0.000***
Procedures	3.29	5.83	(1,104)	0.58	0.448
Perceived Creativity			(6,206)	0.92	0.483
Treatment x Gender			(3,102)	0.60	0.616
Treatment x Perceived Creativity			(6,206)	0.97	0.448
Gender x Perceived Creativity			(6,206)	2.30	0.036*
Concepts	43.93	8.53	(2,104)	5.15	0.007**
Rules	17.83	7.20	(2,104)	2.47	0.089
Procedures	2.61	5.83	(2,104)	0.45	0.640
Treatment x Gender x Perceived Creativity			(6,206)	1.49	0.183

Two-way Interactions: On both tests, there were no significant interacitons between treatment and gender or between treatment and Perceived Creativity. However, there were significant interactions between gender and Perceived Creativity attributed to Concepts in the Achievement test and to all three parts of the retention test. On the Concepts part in both test, boys with either a low or high level of Perceived Creativity scored significantly higher than the corresponding firls, while achievement scores of students with an average level of Perceived Creativity did not differ significantly between boys and girls. On each of rules and Procedures parts of the retention test, boys with a low level of Perceived Creativity achieved significantly higher than respective girls, though there were no significant differences otherwise.

Three-way Interactions: There were no significant 3-way interacitons on either achievement or retention.

Table 3. Analysis of Retention

Effect	ms	error ms	df	F-value	significance
Treatment			(3,91)	0.11	0.953
Gender			(3,91)	3.12	0.030*
Concepts	60.99	9.24	(1,93)	6.60	0.012*
Rules	64.80	7.53	(1,93)	8.61	0.004**
Procedures	9.82	5.61	(1,93)	1.75	0.189
Perceived Creativity			(6,184)	1.40	0.216
Treatment x Gender			(3,91)	0.66	0.579
Treatment x Perceived Creativity			(6,184)	1.34	0.242
Gender x Perceived Creativity			(6,184)	3.38	0.003**
Concepts	29.00	9.24	(2,93)	3.14	0.048*
Rules	29.37	7.53	(2,93)	3.90	0.024*
Procedures	39.84	5.61	(2,93)	7.10	0.001***
Treatment x Gender x Perceived Creativity			(6,184)	0.71	0.641

Motivation and Learning

Results of the analysis for the interaction between intrinsic motivation and achievement are reported in Table 4.

Table 4. Motivation and Achievemnt

	Challenge		Curiosity		Control		Fantasy	
	r	p	r	p	r	p	r	p
Concepts	0.23	0.049*	-0.13	0.176	0.27	0.029*	-0.12	0.211
Rules	0.20	0.081	0.08	0.291	0.25	0.041*	0.24	0.045*
Procedures	0.02	0.441	-0.02	0.440	0.19	0.096	-0.09	0.266

There were significant positive correlations between Challenge and Concepts, between Control and both Concepts and Rules, and between Fantasy and Rules. Curiosity did not correlate significantly with any learning factor, and Procedures did not correlate significantly with any motivation factor.

DISCUSSION

While the students who learned their algebra using Mission: Algebra scored slightly higher in total than those using the worksheets, the difference in mean scores was not significant on either the post-test or the retention test. However, the control activity was a highly intensive learning experience. Yet, the fact that the experimental group achieved at the same level as the control group leads to the conclusion that the learning produced by the highly charged and intensive activity produced by challenging the students and sustained by significant individual teacher interaction can be induced in a more leisurely manner (for both students and teacher) using the Mission: Algebra microcomputer game. This may turn into an ideal learning environment if one takes into consideration the absence of any significant interaction between treatment and the other factors, which would indicate that indiscriminating instructional microcomputer games can be constructed and integrated effectively in classroom activities.

There were no significant differences in achievement or retention among the three Perceived Creativity groups. this result might be attributed to a possible ceiling effect (the mean Perceived Creativity score of the students was significantly higher than the norms obtained by Williams). However, this factor played a role in deciding significant gender differences in mathematics achievement (table 2) and retention (table 3) of 10th-grade students.

Gender differences in mathematics achievement at the secondary school level have been a controversial issue. In this study there were gender differences in achievement and retention, favoring boys. Fennema (1978) argued that such differences are caused by the fact that fewer females elect to study mathematics at the secondary school level, which in turn is caused by females' lesser confidence in learning mathematics and to a belief that mathematics is not useful for them.(1) Helson (1971) argued earlier that such differences reflect social roles and institutional arrangement more than fundamental creative traits.

Results of the current study add to these arguments that self-perception of creativity of both boys and girls is related to their achievement in mathematics. The result that persisted is that boys and girls with an average level of Perceived Creativity achieved about the same scores on both tests, while significant differences appeared at the extremes. However, the relationship remains unclear and needs further investigation.

For the experimental group, intrinsic motivational effects of the instructional game correlated positively with achievement: Challenge correlated with the learning of Concepts, Control correlated with the learning of both Concepts and Rules, and Fantasy correlated with the learning of Rules. Curiosity did not correlate with any learning factor. In their earlier study of the motivational effects of Mission: Algebra, the authors detected a significant increase in Control, a marginal decrease in Curiosity, and marginal increase in both Challenge and Fantasy between the first and second playing them. Playing Mission: Algebra has been a novel experience to them. They started with limited knowledge about the game and soon started to seek more knowledge

(1) A survey by the Association of Universities and Colleges of Canada (AUCC), reported in University Affairs (1990), revealed that, although the number of women enrolled in engineering and applied sciences in Canada jumped dramatically in the past decade, the proportion of women attending these fields was only 13% at the undergraduate level and 12% at the graduate level in 1988. In mathematics and physical sciences, their enrolment accounted for 27% at the undergraduate level and 20% at the graduate level. The picture was quite different in other fields.

about it. Here, one can argue that curiosity arises naturally at this stage while learning the contents of the game is minimal. As the learner gains playing experience, the motivaitonal effect of Curiosity diminishes. By the time the achievement test is administered, the relationship between Curiosity and cognitive learning outcomes becomes blurred.

As knowledge of the game and playing skills build up, students start to use built-in game options more effeciently. The playing experience gained and the amount of knowledge obtained at a certain stage allow for Challlenge to build up slowly. At the same time, students will have more learning experience. With the achievement level attained so far, positive correlation (significant with Concepts only) between the motivational effect of Challenge and cognitive learning outcomes will be established even though this effect diminishes with more playing. Yet, it may be worth noting that Challenge correlated with cognitive learning outcomes decreasingly in the following order: Concepts ($r = 0.23$), Rules ($r = 0.20$), Procedures ($r = 0.02$). This pattern (which is repeated for Control) needs further investigation.

At some later stage, the learner understands the challenge more and a desire for control starts to build up as the learner starts to seek power over the environment to meet the challenge. In the mean time, the student is exposed to even more learning experience. Thus, as both the motivational effect of Control and cognitive learning develop together to optimal levels, positive correlation between them is more clearly established. As with Challenge, Control correlated with cognitive learning outcomes in a decreasing order as follows: Concepts ($r = 0.27$), Rules ($r = 0.25$), Procecdures ($r = 0.19$). The desire for control normally fades as the learner masters control over the game.

Fantasy correlated positively with Rules, while its correlation with Concepts and Procedures was insignificant. The relationship between Fantasy and cognitive learning is unclear here. One can argue that the fantasy of saving a sister space ship lost in space might have existed at a certain stage of playing the game. Yet, the relevance of this factor to learning remains ambiguous. Fantasy can be an important motivational force, but it was instructionally irrelevant in the current study. In general, Fantasy as a motivation may remain in the background of playing the game, yet it is not effective with activities that involve calculation, estimation, or symbol manipulation.

The relationship between intrinsic motivation and cognitive learning may in general be interpreted within the principle of learner control developed by a number of computer-based systems. The principle in general suggests that "the size of the effects on learning of the use of choice and other forms of learner control to increase student motivation will vary with the extent to which control is provided over instructionally-critical aspects of the activity" (Lepper and Malone, 1987). Control may be instructionally relevant or irrelevant, but limited choice is ideal for learning. In the current study, students had no control over the instructional game initially, but later on they could choose or design their own missions.

It is generally believed that motivation enhances achievement. These results indicate that overall motivation can be manipulated sequentially by its factors. Curiosity and Challenge set up the stage for Control that proved to be an effective motivational factor in the game. The indication is that performance may be enhanced in a microcomputer game environment if the motivational level is maintained or increased in its factors.

Thus, software designers would do well to design learning games so that these factors are manipulated. First, learner control should have limited choice and be instructionally relevant. Second, the motivational factors of Curiosity, Challenge, and Control should overlap and peak consecutively - maintaining a high motivational level for the longest possible time; the motivation must persist long enough for the student to meet the achievement goals. And third, Control can be used, but Fantasy should not be used with calculation, estimation, or symbol manipulation.

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مخرجات التعلم المعرفي في ألعاب الكمبيوتر التعليمية

د. عبدالله شعبان
مشروع المدرسة العلمية – قطر

د. مارف وستروم
جامعة بريتش كولومبيا – كندا

الملخص:

يهدف البحث إلى دراسة أثر استعمال لعبة كمبيوتر تعليمية تدعى «مهمة في الجبر» على مخرجات التعليم المعرفي الخاصة بها (ممثلة بالعوامل التالية: المفاهيم - القواعد - الإجراءات) وكذلك دراسة العلاقة بين هذه المخرجات ودور اللعبة في استثارة الدافعية الذاتية (ممثلة بالعوامل: التحدي - الفضول - التحكم - الخيال). لم ينتج عن الدراسة أي فروق في درجات التحصيل أو الاحتفاظ بين الطلبة الذين تلقوا تعلمهم باستخدام اللعبة التعليمية وأولئك الذين تلقوه باستخدام صحائف عمل عبر أنشطة صفية مركزة، ولكن الذكور حصلوا على درجات أفضل من الإناث في كلا الاختبارين. وأشارت النتائج إلى وجود تفاعل ذي دلالة إحصائية بين متغيري الجنس والابتكارية المدركة في قسم المفاهيم من الاختبار التحصيلي وفي الأقسام الثلاثة من اختبار الاحتفاظ. كما تم الحصول على علاقات ارتباطية إيجابية بين المفاهيم وكل من التحدي والتحكم، وبين القواعد وكل من التحكم والخيال. تبين هذه النتائج أن بالإمكان استغلال الأثر الإجمالي للدافعية وذلك من خلال تسلسل عواملها. أي أنه يمكن غرس الدافعية وتقويتها بحيث تتابع عواملها تداخلياً باستخدام جاذبية الفضول بداية، انتقالاً إلى جاذبية التحدي، وانتهاء بجاذبية التحكم.