DYNAMICS OF LEARNING AND MISLEARNING IN A SIMULATED MICRO-WORLD

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Abstract

This paper presents an overview of research on children's learning processes in a computer implemented micro-environment. A class of fourth and fifth grade children played a set of "shark shooting" games as part of their regular school activities for a three month period. The games required the estimation of numerical values on number lines, and the coordination of vertical and horizontal dimensions. Observations are made concerning variations in the development of game skills, and transfer of number concepts to non-computer activities. Discussion focuses on transcript analyses revealing specifics of learning processes during play. Interactions among cognitive skills, game features, and the role of goals in structuring conceptual development are discussed.

Introduction

At the Laboratory for Comparative Human Cognition at the University of California in San Diego, several of us have been investigating cognitive implications of the use of micro-computers in elementary classrooms. Some of this work has concentrated on the use of computers as learning environments. In order to understand how learning occurs in these environments, we have found it necessary to look closely at the details of the interactions among the children, the various helpful adults in the room, and the computer itself. In this paper we describe a study of learning in a simulated micro-environment in which we take a close look at the qualitative differences in performance between the most and least successful players.

A well known example of a simulated micro-environment is diSessa's dynaturtle which behaves strictly according to Newton's laws of motion.

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The main idea behind the use of such simulations is that they embody general principles and relationships in the material to be learned and permit a kind of exploratory behavior that is not usually possible when the same material is presented in standard, expository written or spoken formats. Students explored the properties of this Newtonian object by manipulating it and developing strategies to manage it. Exploration is not simply a matter of trial and error, as might be encountered in drill and practice. In a computer implemented simulation feedback from an error or an exploratory attempt is informative. That is, it not only provides information about accuracy, but gives additional information about relationships embedded in the micro-environment.

The type of simulation we will be concerned with here takes the form of an educational game. Games such as these usually simulate micro-environments which incorporate a goal. In the dynaturtle game, for example, the Newtonian turtle is to be guided to a specific "port", or in another version, around a circular track without crashing. The point of introducing game versions of simulated environments is that they require players to develop and sharpen cognitive skills in the service of attaining the game goal. Because of the inclusion of goals internal to the system, games are more able to stand alone than are pure simulations which students manipulate to achieve externally derived academic goals. The inclusion of internally defined goals also affords the opportunity for an internal tutor function. Since the program can assume that the goal of the player is the internally defined goal of the game, it can monitor the effectiveness of the player's performance. This allows the program to recognize and respond to errors by offering hints, and can alter game parameters to adjust automatically to different levels of skill.

The Shark Games

Working on the notion of exploratory activity, several of us have developed a family of three estimation games called the "Shark Games". The games are intended to strengthen children's knowledge of numerical relationships. Earlier work by us and by other researchers had found that fundamental concepts of numerical rela-

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tionships are often weak among poor achievers in arithmetic1. We hoped that these games could strengthen these fundamental concepts directly, and that this would in turn affect classroom arithmetic skills.

All the Shark Games utilize the same game world - sailing on the high seas, hunting down and harpooning sharks. All three games require estimation along two dimensions marked by numerical scales (see Figure 1). All three of the games were used in our research, though for the sake of brevity only one, called "Sonar", will be described here. In Sonar, the player is sees a pair of coordinate lines - one horizontal and the other vertical - on the screen display. The location of an invisible (underwater) shark is indicated by a pair of numerical coordinates written at the top of the screen. Using these coordinates, the player must estimate the shark's position visually. Each dimension is dealt with in turn, first the horizontal estimate (labeled "aim") then after the aim is set the vertical dimension (labeled "distance") is entered. In effect, each of the coordinate lines serves a dual purpose, as an axis on one dimension and as an indicator marking a numerical selection on the other dimension. The player uses game-paddles (though keyboard entry is a possible option) to move indicator lines indicating the position he thinks is specified by the numerical information. The paddle button (or RETURN) is pressed to "set" each numerical estimate once it is made. To avoid the confusion that can arise from the dual role of each axis line, while each dimension is being estimated, the endpoint numbers and label on the other axis line (now acting as an indicator) disappear.

The "throw" of the Harpoon, "hits" and "misses" all are represented in an interesting graphic display with sound accompaniment. Once both dimensions are entered, a "harpoon" moves from the bottom of the screen to the point specified by the intersection of the horizontal and vertical estimates. Feedback is in the form of a "splash", visually specifying the actual location of each throw. The splash is labeled with its actual numerical coordinates and remains visible on the screen as an additional point of reference through the next several tries.

The games also perform a tutor function. When a player's shot misses the shark, verbal and directional hints are written at the top of the screen. When a player's estimate is too high, the word "smaller" with an arrow pointing in the direction of lower numbers (<=) for that dimension. If the estimate is too low, the screen displayes "bigger" with an arrow pointing in the direction of higher numbers (=>) for that dimension.

To adjust for variations in skill, the games all included multiple levels of difficulty such that the computer took over some functions at the easier levels. This was accomplished by creating "beginner" levels in which only one axis (horizontal or vertical) is used, while higher levels involve two coordinates. Difficulty on the two axis games is varied by reducing the size of the shark with respect to the numerical span of the axis, thus requiring progressively more accurate "thows". Movement to higher or lower levels on successive games is automatic, contingent upon rate of success.

The Study

Our original purpose in carrying out the study was to examine the possibilty of transfer of game-related skills in numerical estimation to other kinds of numerical manipulations, particularly paper and pencil tests of number line skills and classroom arithmetic. It is impossible to overlook the variation in academic achievement that is typically found in most elementary school classrooms. For this reasons, we were also interested in finding out how learning to play the simulation-games themselves interacts with these differences in academic skill. Thus we were looking for a two-way effect, game skills transfering to classroom performance, and academic skills affecting the ability to become skillful in the game.

Two structural aspects of these games were particularly interesting to us from a theoretical perspective. One is the inherent requirement for successive approximations2, and the other is the introduction of cartesian coordinates requiring the coordination of two dimensions. Strategies which use successive approximation are encouraged by the game setup which allows for multiple tries (or throws) with informative feedback accompanying each miss. The coordination of estimates with respect to the two axis system was accomplished through a social coordination between two players. Children usually played these games in pairs, one child of each pair playing one of the dimensions. We were interested in the way that the social coordination of action might serve as a basis for spatial coordination on a two-dimensional plane.

With all this in mind, we placed the Shark games in a combined fourth-fifth grade classroom where they were used in a computer-based "center" scheduled to be visited by specific pairs of children each day. In this way, all the children in the class were able to work with the Shark games on a regular basis, amounting to about one half-hour per child per week over a period of three months. The Sonar game was first introduced into the classroom with a range of 0 to 100 on each axis.

At the first session, and at several important transitions throughout the study, an observer/helper attended the children's shark game sessions. As the term implies, the helper/observer had a dual role. One role was to record events as they occured during game play. The other role was to help the children if they encountered any major difficulties preventing them from effectively playing the games. The specifications of the helping role were to keep the game going while interfering as little as possible. A graded sequence of hinting procedures was to be used when intervention was necessary. First, the observer/helper was to simply point out relevant information on the monitor screen. Then, if that were not enough, point out relevant relationships between game elements. And finally, if all else failed make suggestions about what to do.

Several kinds of data were collected on game play itself. The games had been set up to record all sequences of keypresses, all game parameter values, and time information from an internal clock. This data was taken on all games played throughout the study. There were also the audio-tapes and field notes taken at several transitional points during the study. The audio-tapes recorded conversation and other sounds and could later be coordinated with the written field notes and computer collected records.

Results

General Trends

Most children increased their skill at playing the shark games themselves throughout this time period, though there was considerable variability among children in how well they played. Our findings showed the classic pattern - those who played relatively well in the beginning also improved more than those who played more poorly on the first few attempts. Nevertheless, even with the skilled players, we could find no overall transfer of game skill to paper and pencil tests which assessed number line and written arithmetic skills.

These findings were quite disappointing since we had developed these games specifically to help the poorer students, and had hoped that game derived skills would show transfer to some paper and pencil tests. We decided to look at the children's game playing in some detail to find out what had actually happened.

A preliminary analysis has been done on the keypress data for the initial session and on overall achievement within the game itself throughout the study. Overall game achievement was assessed as the percent of sessions in which the players attained level 6 or better (out of a possible 9 levels). This method of scoring overall game achievement resulted in scores for 19 individual children ranging from 10 to 90%. We then designated the 7 players who scored over 70% as "high", the 6 players with scores between 40 and 69 as "intermediate", and the 6 below 30% as "low" in overall game achievement. (There were no scores between 30 and 40 percent.) This presentation concentrates on the contrast between the high and low game players. We found that in the introductory session low achievers overall had spent more time on the single-dimension lower levels; used more "throws" per game to hit the shark; and showed a much higher average deviation of throw values within each game. In general, the overall poorer game players appeared to be less systematic in their initial approach to the games.

Transcript Analysis

In order to account for these data, we looked at the interactions among the players, the observer/helper, and computer as recorded by our audio-tapes and field notes. We found that there were at least two major ways that game strategies differed between players ranked as good or poor in overall game achievement: the emphasis on numerical judgements in making game decisions, and the ability to learn and manage the mechanics of the game. Differences in the use of numerical strategies were striking. The better players used numerical specifications frequently as a way of explaining thier own actions or specifying some game related information to another player. But numerical judgements did not substantially enter into the remarks or game decisions of the poorer players.

It is not surprising that players with poorer number concepts should use numerical information less than those with better understanding of numerical relationships. But the mechanics of the shark games should be just as unfamiliar to all the children, regardless of numerical skills. Nevertheless, the poorer players also appeared to have more difficulty adjusting to the mechanics of playing the game itself - how to set up and execute the shots, coordinate the actions of both players on the two-dimensional levels, and so on. Could the lack of certain conceptual knowledge interfere with the ability to learn the mechanics of a game in which that knowledge must be employed? Or is there some other reason, perhaps some fundamental problem underlying both poor mathematical ability and game learning ability?

The data from this one study can not provide definitive answers to these questions. But an analysis of the details of the children's actions in the games reveals some interesting relationships among cognitive skills, understanding of specific relationships among game elements, and recognizing the goal of the game.

All the children in this study quite easily recognized the main goal of the game - to shoot a shark with the harpoon. There appeared to be no difficulty accepting the moving arrow as a harpoon or the idea of a hidden shark which, when hit, appears momentarily as a small triangular dorsal fin. The unanimous acceptance of this game goal, however, masks a host of ambiguities which only become apparent from the children's remarks and questions addressed to each other and to the observer/helper. Because the misconceptions arising from these ambiguities prove to be functionally related to the development of cognitive skills, two representative examples of these misconceptions are discussed here at some length.

Some Failures: Several children showed considerable difficulty even on the low level single-dimension games. After completing seven single-dimension games and in the middle of multiple attempts to hit the shark during the eighth game, one such child asked if the shark were "roaming around in there". In this context, the remark suggested that the player thought the shark was a moving target, invisibly swimming across the screen. Such a notion could derive from repeated frustrated attempts to estimate the shark's position, or it might be a misconception from the start. After all, sharks are not characteristically stationary, especially when under fire. However it arises, the idea of a moving target calls into question the player's understanding of the relevance of the numerical specification of the shark's position. If the shark is moving, then the numerical information is no longer relevant, and Sonar becomes a guessing game in which the "smaller", "larger" hints provide the only clues. This pattern essentially characterized the game playing of several of the poorer players. Instead of using numerical information to progressively narrow down the search for the shark (the process of successive approximations we were interested in), these players simply used the directional information from the hints without calibrating the distances or coordinating successive tries in any way at all.

Notice that this erroneous conceptualization makes fundamental changes in the underlying goal of the game. Specifically, it makes irrelevant the major goal that the game is intended to support: get as close as possible to the position on the screen which corresponds to the numerical coordinates printed in the upper part of the display. When a player does not recognize the goal of a game, no amount of practice will bring him closer to achieving it. The child has missed the point and is simply playing a different game, one involving different skills, strategies and goals than those intended by the game's designer.

There were many other technical pitfalls that lead to major misconceptions about the game and its goals. One which proved to be a destructive factor as the game progressed concerned the function of the RETURN key. Programmers and users of software tend to have differing views of the function of the RETURN (or ENTER) key. From a user's point of view, the RETURN key appears to initiate an action, to start something. Where the programmer intends the RETURN keypress to tell the program to read a line of characters just typed in, the user sees it as a keypress that directly starts an action. The tacit assumption on the part of a naive user is that the computer is reading along as information is entered at the keyboard or other peripheral input device. The RETURN key simply starts the next machine function.

In the Shark games, the introductory text and instructions end with the instruction: "Push RETURN to start a game", further reinforcing the idea of RETURN as "begin". Not surprisingly, more than one of the children in this study treated the RETURN key as an initiator. In at least on case, this became a rather pernicious bug in the child-computer interactions. The problem first showed up when one child in a pair of players read aloud the screen instruction: "Set the aim, then push RETURN." The second child then repeated the instruction in the following form: "Then push RETURN? Push RETURN? Then I start the aim?" Though the first child and the observer/helper manipulated the situation so that the aim was at least sometimes set before RETURN was pressed, the "RETURN starts things" idea persisted into the higher, two-dimension levels of the game. This player would then press RETURN to "start" her partner's turn, thereby firing the harpoon before he could make any move to set his own aim. This short-circuited the possibility of cooperative, coordinated activity and the children in this case (as in at least one other) persisted in thinking they were playing competitively against each other. The goal of coordinating two dimensions was never established.

These examples are typical of the difficulties the poorer players had learning the mechanics of the Shark games. In some cases, specific misconceptions were quickly corrected by adult intervention. In other cases, misconceptions persisted through several sessions and some were never resolved. These technical difficulties, though they are not directly related to the concepts we wanted the children to learn, reorganized the dynamics of the games so that they no longer addressed the relationships the programs were intended to embody.

This line of reasoning suggests that technical misconceptions on the part of some players reduced the effectiveness of these games in promoting the development of numerical concepts. But evidence from the better players indicates that the causality implicit in the above statement might also run the other way. Weak numerical concepts might have left the poorer players open to technical misconceptions by not providing a coherent framework to guide learning of the game.

Some Successes: In the introductory sessions, as in subsequent ones, the better players overtly and verbally refered to numerical information in all aspects of play: in aiming the harpoon themselves or in guiding each other's actions, "Seventy-eight is about here"; in taking roles in two- dimensional play "You got sixty-four", and so on. This often lead to successive approximation strategies. After two misses, for example, one player remarked, refering explicitly to the value of the second miss and tacitly to the first: "Twenty-one. We have to be right between here."

The numerically specified position information and the familiar (though tacit) numerical relationships on the number line provided a coherent structure within which the technical aspects of the game could be worked out. That is, possible ambiguities such as the function of the RETURN key and the nature of the shark's movements are worked out in the service of maintaining coherence within the numerical context. The process of working out the technical details of the games usually went so smoothly among the better players that it was often difficult to detect transitions to serve as examples. A few observations can be cited here to illustrate the point.

In one case, a player had begun by randomly aiming and shooting across the screen, apparently without regard for numerical information. After two low-level games in this mode, the observer/helper simply pointed out that the shark's position was numerically specified. The player's next aim was again wild, but this time she verbally predicted it's numerical value, saying "That's probably gonna be two." This prediction signaled her first attempt to coordinate position and numerical information, and her accuracy increased steadily with subsequent tries.

In another case, we discovered that a player had not clearly understood that the hidden shark was not a moving but a stable target until his ninth game. Though he had participated effectively in quite accurate and strategic play in all these games, this boy had been setting his aim according to the specified numerical informaton, not recognizing its relationship to the position of the hidden shark. During the ninth game, he expressed surprise that the shark so often turned up where he had shot: "So wherever you hit the thing, it goes?" This player had also assumed that the shark was swimming invisibly around the screen, but in contrast to the previous case where the notion of a moving shark was so debilitating, this boy's playing had been consistently strategic and effective. This was possible because he was using numerical information to structure his activity before he completely understood how all the game elements were interrelated. Ultimately, he discovered the "stable shark" feature because his actions were consistently guided by appropriate goals which were supported by his understanding of the very numerical concepts that the game was designed to teach.

Discussion

Though this very preliminary analysis of our recently gathered data cannot give definitive evidence about learning processes in interactive media, several important points can be made. First, stand-alone simulation-games cannot be considered a panacea for the problem of remediation of low achieving children. The specific game-goal of shooting sharks was not by itself enough to organize behavior in ways that would lead to development of the intended skill. In order to insure that the players interpreted the game the way the game designers had intended, some adult intervention was necessary even for the best players. Initial misconceptions are difficult to alter once they are established3, and can be perniciously detrimental.

It can be argued that these difficulties arose because of flaws in software design or that better tutor functions would more effectively monitor and guide a player's actions. Both of these arguments are probably valid. However, we cannot assume that software - however well designed - will ever be completely free of either of these problems.

When unfamiliar goals are introduced requiring a new application of undeveloped or underdeveloped skills, it can not be assumed that a novice player will apprehend all the relevant relationships among game elements and correctly infer the goal or goals intended by the game's designers, however clearly these goals appear to be presented. If a player infers a wrong goal, then feedback from an automatic tutor is not likely to be effective. This feedback is only corrective with respect to those goals the game designers intended. But players would interpret such feedback in terms of their own intentions. If a goal is misconstrued, then automatic tutor functions are rarely adequate to correct it. Continued practice in the game rarely corrects this misunderstanding and usually causes it to be more deeply entrenched. At the same time, since changes in game goals alter the dynamics of the game itself, the skills and strategies that are being developed through practice may not be those which the designers of the game or the teacher intended.

These principles might at least partly explain the lack of transfer from game playing to paper and pencil analogs of number-line estimation tasks. With inadequate supervision at entry into the game environment, children whose number line skills were too poor to provide a way of recognizing the salient structures of the game did not play the game as it was intended to be played. They effectively rearranged the dynamics of it to avoid practicing those skills we wanted them to develop. Children whose number concepts were sufficiently strong to recognize the salient relationship expressed numerically generally did learn the game as it was intended, but did not need to improve those skills very much to play. At least not enough to be detected by pre- and post-tests.

Conclusions

The function of education is to transfer to children socially organized and formalized knowledge - in the case of this study, the number system and the arithmetic and coordinate systems based on it. Thus far, our analysis is able to show that when these knowledge systems form the basis for a simulation or simulation-game, players must rely either upon prior familiarity with that system, or external guidance to discover the relevant parameters for manipulation. We expect to show from further analysis and in future research efforts that once this basic understanding is established exploratory activity can be productive.

Beyond this, our observations have implications for educational practice. They suggest that it is important to consider the role of the teacher when investigating the dynamics of child-computer interactions. The use of computer-based media might provide a new role for teachers. With computers, parameters and rules for manipulation are internal to the machine. They are not unambiguous, and novices - either children or older students - need help to learn to manipulate them effectively. Because of this, the teacher can become an ally and helper to the student, a role which contrasts to the usual one of task master and judge. Future research should investigate the potential of this teacher-student-computer interaction system in which the teacher's competence serves as a resource for students in problem solving situations.

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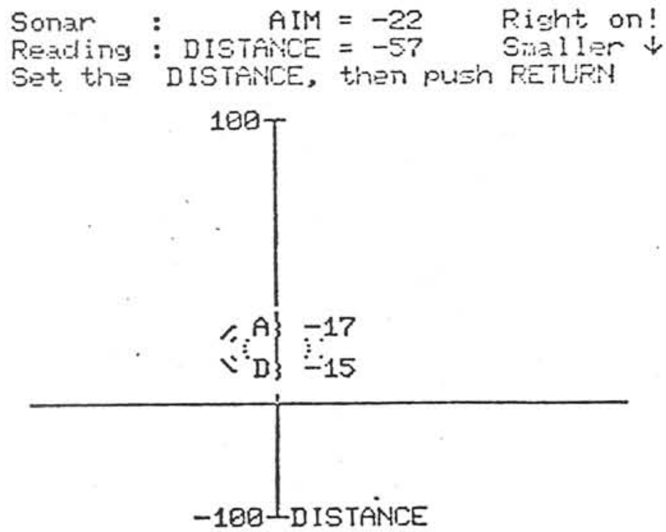

Figure 1

This is a typical screen display in Sonar. The numbers at the center top of the screen indicate that the shark is hidden at -22 on the AIM (horizontal) line and -57 on the DISTANCE (vertical) line. The player has already made one shot which has left a "splash" (ragged concentric ovals) at -17 on the AIM dimension and -15 on DISTANCE. Verbal hints appear to the right side of the top of the screen. "Right on!" indicates that the AIM estimate (-17 showing in the "splash") was close enough. "Smaller" indicates that the DISTANCE estimate (-15 showing in the splash) needs to be revised downward. The downward pointing arrow indicates the direction that the indicator line must be moved.

Note that the AIM line is not labeled here. This is because the player is in the process of selecting an estimate on the DISTANCE dimension and the AIM line is for the moment acting as an indicator rather than a numberline.