Visualizing Problem Solving in a Strategy Game for Teaching Programming

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Abstract - Lack of problem solving skill has been identified as the major cause of students’ failure in introductory programming courses. This paper presents a strategy game, COPS, which helps students improve their problem solving ability by building program flowcharts as a jigsaw puzzle. For each move, pseudocode equivalents are immediately generated by the system. Students therefore have two visual representations of the problem solution and can more easily follow the logic in their solution. COPS provides dynamic feedback using visual and textual aids to guide students throughout the process. The results of two studies done with secondary school students in Trinidad and Tobago using COPS had positive results.

Keywords: COPS, problem solving, visualization, educational game, flowchart, programming

1 Introduction

The high failure rates in introductory programming courses around the world are evidence of the difficulties which students face with computer programming. Researchers have offered many reasons for students’ failures such as poor mathematics skills and poorly designed instruction methodologies; however, low problem solving skill has been highlighted as their major challenge [1], [2], [3]. Students also have difficulty with program comprehension, program generation and programming fluency but their lack of problem solving skill remains their biggest challenge.

Problem solving requires that students be able to understand the problem and what is required, determine the steps required to solve the problem and know the right order of the steps, and choose between different solutions. The main tools use during problem solving for the algorithm representation and development are flowchart and pseudocode. Pseudocode is a text based representation which consists of English-like statements. It is designed to fill the gap between the informal (spoken or written) description of the programming solution and the final program code [4]. Flowcharts are a visual representation of program flow using a combination of arrows and symbols to represent the actions and sequence of the program.

2 Collaborative Online Problem Solving (COPS)

COPS is a web based strategy game in which players are required to solve program flowchart puzzles. COPS has both single player and multiplayer modes but the game objective is the same. The multiplayer version was designed based on a framework presented by Bachu and Bernard [10]. The primary target users of COPS are adolescents between the ages of 13 and 17 since most students in Trinidad and Tobago and the wider Caribbean region are introduced to programming at the secondary school level. This suggests that students’ difficulties need to be addressed at that level rather than at a university. Also, improving the situation at an earlier time would increase the likelihood of students being interested in pursuing higher education in computing.

Both flowchart and pseudocode are important tools for the teaching and learning of programming. Students have a greater preference for flowcharts [11] and flowcharts have been useful in the understanding of complex algorithms [12], while pseudocode helps students translate their solution in program code. COPS utilizes both flowchart and pseudocode.

2.1 Gameplay

There are two different puzzle types in COPS which are designed to challenge players differently:
Figure 1 COPS Multiplayer Swap Screenshot

Figure 2 COPS Multiplayer Jigsaw Screenshot
1. SWAP – The players are presented with a flowchart with pieces out of order and they are required to swap two pieces at a time to correct the flowchart. The players are given a target number of moves in which to solve the puzzle. This puzzle type was designed to be the easier of two to allow players to gain a sense of accomplishment so they are confident to attempt the harder puzzle type.

2. JIGSAW – The players are required to build a flowchart similar to building a jigsaw puzzle within a target number of moves.

Figures 1 and 2 show screenshots of COPS multiplayer swap and jigsaw games, respectively. The layout of the single player game is the same except that there are no group members, chat or group areas. In both modes, players are presented with a problem description and they are required to build the correct flowchart to solve the problem.

Each puzzle in COPS has a difficulty level and a question type. The questions type corresponds to key concepts in introductory programming: arithmetic, if statements, if-else statements, while loops and while loops with if-else statements. Players are awarded points based on the number of moves in which the puzzle is solved. Players receive 10 points for each swap puzzle which they complete within the target number of moves and 20 points for jigsaw. One point is deducted for each move beyond the target. For games which they quit, no points are awarded. In the multiplayer version, group sizes are between two and four and one player is randomly chosen to make the first move and a turn base approach is used. All members of the groups receive equal points for a game. Players are allowed to play within different groups to increase their point accumulation.

2.2 Design of COPS

Games which are successful at teaching programming are those which cause the learner to develop and understand concepts from the content as a consequence of its system and interface [13]. All aspects of COPS have been designed to help students improve their knowledge and use of flowchart and pseudocode in problem solving. These tools have been used in classrooms for many years but most students have a preference for one or the other. COPS helps students develop a greater appreciation for how both can be used in designing the logic of the program solution as well as to understand how they complement each other. A space theme was used throughout COPS along with bright colors to make the game appealing to its target users.

The shapes used in the flowchart puzzles throughout COPS are the standard program flowcharts; a purple arrow for sequencing, a blue oval for start/stop, a yellow parallelogram for input/output, a red rectangle for process and a green diamond for decision. COPS has a question bank containing a large number of puzzles of varying types and difficulties. Each puzzle is chosen based on the current cumulative points of player and the difficulty level of the puzzles. All new players are allowed to attempt questions of difficulty level 1 (Very Easy); to attempt questions of increasing difficulty, their minimum point accumulation should be as follows: level 2 (Easy) – 50 points; level 3 (Intermediate) – 100; level 4 (Hard) – 150 points; level 5 (Very Hard) – 250. The puzzles for the groups are chosen based on the average point accumulation for the members. At difficulty levels 1, 2 and 3, the jigsaw puzzles provide students with the exact number of pieces which are required to build the flowchart; however, at the harder levels, they are given additional pieces which do not form part of the solution. Game administrators or teachers can also choose to limit the puzzles to specific types. This feature is useful as a teaching tool where teachers may wish to limit the puzzles their students can attempt to the current topic they are teaching.

2.3 Visualizing Problem Solutions in COPS

The pseudocode in COPS is automatically generated according to the current flowchart regardless of whether the flowchart is correct. The pseudocode was presented for two purposes; to help players who get stuck with their puzzle and to show students how flowcharts can be translated into pseudocode. This automatic translation allows students to see how changes in program sequencing are represented in program code. This is a powerful visualization aid to their understanding the logic in their solution.

Besides the pseudocode, COPS provides intelligent visual feedback to players to assist them in solving the puzzle. While solving a swap puzzle, the pieces which are in incorrect positions have a black background in contrast to the general light grey/dark grey and when they have been corrected, the background changes to the normal colors. In the jigsaw puzzle, while the puzzle is being built, the correct portions of the puzzle which contain more than three pieces are greyed out to indicate to the players that it is correct to allow them to move onto other parts of the puzzle.

The possible positions where pieces can be placed are highlighted in a black background. The visual alterations which COPS provides are intended to guide the learning process and can also help encourage problem solving [14]. Students generally lose focus easily and get frustrated when they do not receive adequate guidance [15].

Figure 3 shows the pseudocode being updated when two pieces are swapped in swap puzzle game; the last two lines of the pseudocode are interchanged. Figure 4 shows the jigsaw update for a correct move and Figure 5 shows the jigsaw update for an incorrect move. In Figures 4 and 5, the pseudocode is still generated to match the flowchart but the non-greying of the newly
Figure 3 COPS Swap Puzzle Pseudocode Update

Figure 4 COPS Jigsaw Puzzle Correct Mode Update

Figure 5 COPS Jigsaw Puzzle Incorrect Move Update
COPS stores data about every move made in all games, this allows the recreation of the games which can be used for analytical purposes by teachers and students. Additionally statistics such as the following can also be gathered from COPS:

- Performance on tasks by individuals and groups. This can be filtered by puzzle type or difficulty level.
- Performance by individual players and groups. This can also be filtered by puzzle type or difficulty level.

With this information available, students can identify their strengths and weaknesses, reflect on their past experiences and improve their learning. Similarly teachers can use the information to structure their teaching.

### 2.4 COPS System Architecture and Implementation

COPS was built entirely using the .NET framework for easy integration and seamless functionality. The game client was developed between 2011 and 2012 and uses Silverlight 5.0. Silverlight was chosen due to its extensive user interface (UI) and animation possibilities. Silverlight is perfect for developing great looking and interactive web applications such as multiplayer games like COPS. The game server was developed with Windows Communication Foundation (WCF) Duplex Web Services. WCF is a framework for building service oriented applications and duplex communication was chosen to allow two-way communication between clients and server. C Sharp (C#) was the programming language used with Silverlight and WCF. NET.TCP is a TCP-based network protocol provided by WCF for Silverlight clients which facilitates high performance communication. The Database Management System (DBMS) used was SQL SERVER 2008 R2. LINQ TO SQL was used for all database processing. It is a component of the .NET framework which provides a runtime infrastructure for managing relational data as objects. All development was done using Microsoft Visual Studio 2010 Service Pack One, SQL Server Management Studio and Microsoft Expression Blend 4. The game’s server was deployed on Internet Information Services Seven (IIS 7).

The COPS WCF web service was implemented as a singleton. This means that one WCF service instance was created for serving all clients where the different client requests are handled using multiple threads. The COPS Silverlight client was implemented using object-oriented design and a condensed class diagram is given in Figure 6. The visualization logic in COPS was implemented in the Game super class and its subclasses. Figure 7 shows a sequence diagram for each time a player makes a move. The details of each move are sent to the Game server and the details are stored in a database before it is sent to the other group members for multiplayer games. When each game client receives the move details, it updates the game accordingly. During the update, a dynamic programming algorithm is applied to identify the portions of the puzzle which are correct and the appropriate visualizations are applied.

### 3 Data Collection and Results

In August 2012 and January 2013, two studies were done to investigate the usefulness of COPS in helping to increase the problem solving abilities of novice programmers.

The first study had 27 participants from various secondary schools across Trinidad and Tobago, none of whom had done computer programming previously. All participants were required to attend 3 hour class sessions daily for two weeks. Since the students had no programming experience, the first three sessions were used to teach basic problem solving using traditional classroom methods. After the third session, an evaluation exam was administered (PRE-TEST); the participants were then introduced to the multiplayer mode of COPS and the remaining classes employed a blended learning approach where each session was spent using traditional teaching and COPS. The participants also had 24 hour access to COPS outside of the class sessions. Also, the puzzle types which the players were able to access were limited to the topic which was currently being taught. Another exam (POST-TEST) was administered at the end of the sessions. A paired t-test was done on the results of the pre-test and post-test which showed a mean improvement for of 14.27% (p-value=0.000).

The second study had 30 participants who had previously done computer programming at their various schools. A pre-test was administered and all participants were given 24 hour access to the multiplayer mode of COPS for three weeks, unlike the first study, there were no formal class sessions. The aim of the study was to investigate the usefulness of COPS as a revision tool for the topics they would have already covered at their respective schools. At the end of the three weeks, a post-test was conducted. The results of a paired t-test showed a significant mean improvement of 21.56% (p-value = 0.00). Additionally, a two-sample t-test was done using results from study one and study two which showed that while the participants from the second study had a higher mean improvement, a p-value of 0.123 indicated that there was no significant difference between both groups. This finding suggest that COPS was just as beneficial as a learning tool to first time programmers as it was as a revision tool to those who previously done programming.
Figure 6 COPS Condensed Class Diagram

Figure 7 COPS Make Move Sequence Diagram
All participants from both studies were asked to complete a survey to provide feedback about COPS. Some of the major findings related to the visualization techniques were:

- 88% of participants found the automatic translation of the flowchart into pseudocode to be useful.
- 95% thought that the visual alterations in flowcharts helped them solve the puzzle faster.
- 97% thought that continued use of COPS would help them better understand flowcharts
- 89% thought that continued use of COPS would help them better understand pseudocode.

Data collected from COPS also allowed the identification of the type of puzzle which proved to be most difficult and to identify the specific program design problems which were the biggest challenge to students.

4 Conclusions

COPS is a strategy game designed to visualize problem solving using dynamic visual and text alterations. The visual problem solutions helped students to understand the logic in their solutions and the automatic mapping of the flowchart they had built, to its pseudocode equivalent reinforced that understanding. This learning took place in an engaging and motivating game environment. Qualitative and quantitative results from studies conducted have shown that COPS is beneficial to novice programmers. Currently COPS focuses on basic programming concepts but it can be easily extended to include more advanced topics.

5 References


