`tell me to survive`: Concreteness Fading and Visual Programming in Teaching Object-Oriented Programming

Andrew Jiang, Michael Mauer, and David Li

1 Introduction and Motivation

Much effort has gone towards methods to teach programming as an overall concept, with systems like Scratch and CodeSpells demonstrating how visual programming can successfully introduce students to this field. Our goal is to teach the more specific topic of object-oriented programming to novice programmers using these same techniques, focusing on how to abstract and represent ideas such as method definitions, subclassing, and overriding. Additionally, to reinforce these concepts to an audience already somewhat familiar with programming, we will introduce concreteness fading, transitioning students from visual programming to directly writing code. This will facilitate the learning of these specific higher-level concepts and abstractions within computer science, which is important to effectively educate and train the next generation of computer science and software development students.

2 Related Work

The idea of visual programming manipulating robots or other objects in a virtual world is not new; we list several games and projects in the same vein, with some comparison to our project.

- CodeSpells[1]
- Scratch[2]/Alice[3]
- Looking Glass[4]
- Hour of Code[5]
- LightBot[6]
- Human Resource Machine[7]
- Blockly Games[8]
- BlockPy[9]

CodeSpells, Alice, Scratch, and Looking Glass are more free-form; instead of specific puzzles or levels to solve, they simply place the player in a sandbox. Looking Glass has metaphors for object-oriented concepts, and covers more of them than our project does, but does not employ concreteness fading. Hour of Code, LightBot, and Human Resource Machine take the same puzzle-oriented approach our game does, but also lack the concreteness fading aspect. Blockly Games is the most similar to our approach, initially using blocks whose labels transition from text descriptions to code, then changing to a text editor at the end. However, it does not present a consistent game, changing the theme and mechanics every few levels. BlockPy is

[1] `https://codespells.org/`
[2] `https://scratch.mit.edu/`
[3] `http://www.alice.org/`
[4] `https://lookingglass.wustl.edu/`
[5] `https://code.org/learn`
[6] `https://lightbot.com/hocflash.html`
[7] `https://tomorrowcorporation.com/humanresourcemachine`
[8] `https://blockly-games.appspot.com/`
[9] `https://github.com/RealTimeWeb/blockpy`

more advanced, enabling the player to seamlessly switch between code and visual programming (and translating one to the other), but does not use concreteness fading either.

3 Methodology

`tell me to survive` is a purely client-side, web-based game built on HTML5/JavaScript using Python as its instructional language. The core concept is manipulating robots in a game world via visual or text-based programming in order to solve puzzles and accomplish objectives.

3.1 Concepts

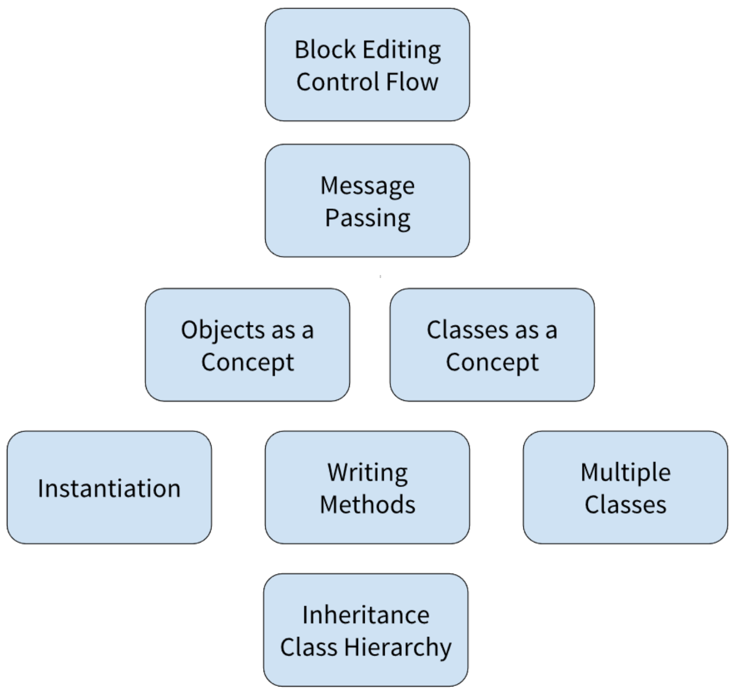


Figure 1: Concept Progression

We limited our scope to the concepts in Figure 1 in order to limit the game length and complexity, and because of implementation constraints. This means that advanced topics such as abstract classes and polymorphism are not covered. This is an acceptable trade-off because the purpose of this game is not to teach OOP in its entirety, but rather to ease the conceptual transition for new programmers.

Figure 1 lists the progression of requisite skills up to mastery of inheritance (our overall learning objective). Mastering a skill in any given level in the diagram should require mastering every skill in the previous level. For instance, using inheritance effectively requires that the user is writing methods across several classes in the hierarchy, then instantiating different types of objects with those classes. These individual skills can then be further subdivided down to the basics of using our click-and-drag block input system.

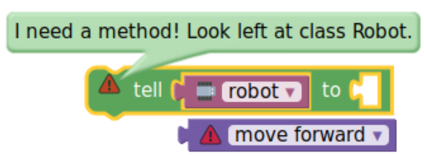
The level progression slowly moves concept by concept through the skill tree, trying to introduce only one new concept per level; otherwise, users are likely to get confused. For example, consider how new robot types are introduced. At first the player must identify that

MineRobot (and other subclasses) can use functions for moving and turning from the basic Robot class. Later on, there are more complex relations, such as the way that FrackingRobot overrides a function from MineRobot. Moreover, as new concepts are introduced, old concepts are recombined to make new puzzles. For example, the HeavyLifter is used in a context such that it needs to use a function defined in the basic Robot class. However, it also requires implementing that method first.

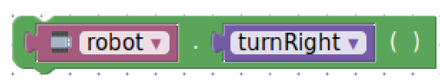
3.1.1 Concreteness Fading

Our fading process has 3 stages. Initially, all blocks start off as textual descriptions of what they do, e.g. “tell _ to _” for method invocation or “create a new _ called _” for object instantiation (see Figure 2a). As the player progresses, the labels on the blocks are faded into actual Python code, as in Figure 2b. Eventually, the player will be given a text editor and asked to write the Python code themselves. Some scaffolding always remains; for instance, the object hierarchy view always remains accessible after it is introduced, and serves as a reference for what classes and methods are available.

Beta testing found that changes to the blocks should not happen while another concept is introduced, because otherwise, players are overwhelmed by the number of new skills required. Thus, some levels introduce no new object-oriented concepts, and instead, pose a simpler puzzle focusing on usage of a newly faded block.



(a) An unfaded method invocation block.



(b) The faded method invocation block.

3.2 Application Design

Through user testing, we simplified our block interface as much as possible. For instance, the repeat block was changed from accepting a block subexpression to just a number. The player does not have access to more complicated control flow such as branches and for loops. In fact, even method invocation was simplified by ignoring parameters and return values. Our goal was to focus more on a basic set of OOP concepts and the corresponding syntax. Thus, we limited access to features that would increase the complexity of solution code, while ensuring that the player must use object-oriented concepts to solve the level.

To further enforce object-oriented thinking, we imposed a block limit. Similar to the way LightBot forces players to define functions due to lack of space, we design levels such that there is no way to finish within the block limit without defining a method. This forces players to consider the class hierarchy and actually implement useful methods they call on objects. Without this restriction, the hierarchy (and thus our goal of teaching OOP) could potentially be disregarded.

One way around this restriction is to code the solution for an entire level inside of a method that has been faded to the code editor. We saw this happen once in our testing. However, in the end, this is actually beneficial because the user is writes more object-oriented python code than originally expected.

3.3 Evaluation

We evaluated the performance of the game by administering a pre-test and post-test to all people who completed the game. Both tests were entirely identical, 5 multiple-choice question quizzes testing both object-oriented Python syntax and general concepts. Each question had one correct answer, and a player's score can be any integer between 0 and 5 inclusive. The goal was to present questions that test for both practical and more abstract understanding. The quizzes were strongly integrated into the game itself, presented as an "Robot Commander Aptitude Test" and a "Robot Commander Proficiency Test".

We targeted students who are currently enrolled in or have taken only an introductory programming course. The game was advertised in CS 1110 (Spring 2016) at Cornell, and at Sparta High School, as well as to specific students who have taken CS 1110 here. In general, we looked for some procedural programming experience, with some or no object-oriented experience (e.g. CS 1110 but not CS 2110).

4 Results

Our results are partially open data: all analysis scripts are under the same license as the project itself (AGPLv3) and anonymized data is available as well (random user IDs and completion time stats). This is available in a separate repository, `https://github.com/lidavidm/cs6360_analysis`.

4.1 Pre- and Post-Test

12 people completed the game and the post-test. The mean pre-test score for those 12 people was 3.167 (s = 1.267). The mean post-test score was 4.25 (s = 0.754). We performed a paired t-test on the pre-test scores and the post-test scores, and we found that the difference in means was statistically significant, $t(11) = 3.767$, $p = 0.003$.

These results suggest that by playing the game, the players improved their understanding of the concepts tested by the 5 questions, namely classes and objects, method calls, initialization, inheritance, and overriding. Thus, we can reasonably claim that the game is successful at teaching some of our proposed learning objectives. Looking specifically at which questions did or did not improve after playing the game, we can run McNemar's test on each individual question. (This test compares paired binomial data; in this case, we are comparing the proportion of users who got the question right before and after on each individual question.)

Question	Concepts	Significant?	p	χ^2
1	Inheritance	No	0.2482	1.333
2	Instantiation	**Yes**	0.0133	6.125
3	Method invocation	No	0.1336	2.250
4	Overriding	No	0.4795	0.500
5	Subclassing	No	0.4795	0.500

Thus, we improved post-test results significantly on only one question, dealing with object instantiation. This lines up with our mean scores, which improved by approximately a point.

A potential confounding factor is that the correct answer to the second test question can be inferred based on example code provided in later questions. Specifically, the second question tests whether the player understands the need for an object to be initialized and the required Python syntax, but later questions show the player correct initialization code in different contexts. In other words, learning of initialization and the related syntax may have occurred during the pre-test and not while the game was being played. The same could be said for question 3, which requires knowledge of method call syntax; questions 4 and 5 display correct method call syntax in question descriptions.

One possible way to address the above problem is to form a control group. The control group would take the pre-test, do something unrelated for about an hour (an anecdotal estimate of the time it takes a typical member of the target audience to complete the game), and then take the post-test, which is identical to the pre-test. This would help us approximate the amount of improvement that can attributed to the pre-test alone. Unfortunately, due to time constraints and difficulty finding volunteers who fit the target audience description, we were not able to include a control group in this study.

Another point to be wary of is when the pre-test and post-test were completed. Since the game was also distributed through the Internet and progress is automatically saved in the browser cache, the pre-test, game levels, and post-test did not all have to completed in a single session. For example, one of the players included in our analysis finished the post-test about five days after they finished the pre-test. In these cases, playing the game was not the only activity that occurred between the completions of both tests, and those other activities could have also contributed to learning.

4.2 Subjective Impressions

Our post-test also included four extra questions that were opinion-based. Three of those consisted of asking the player how much they agreed with the following three statements.

Statement	Mean score
I enjoyed this game.	1.08
Before playing, I knew object-oriented programming.	0.0
After playing, I knew object-oriented programming better.	1.25

The mean scores were obtained by mapping the five possible answers to integer values as

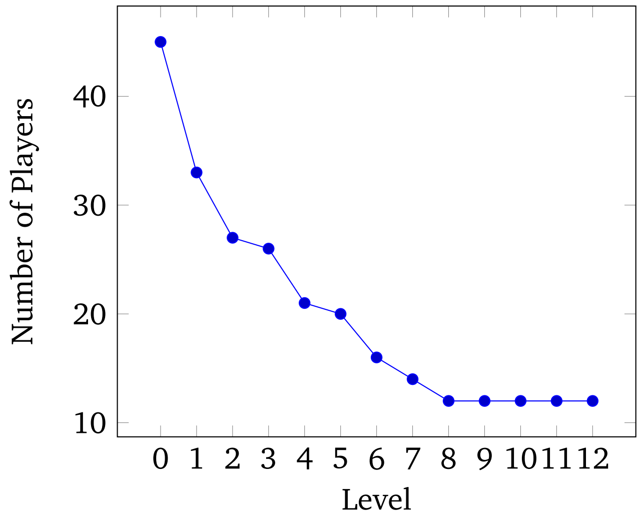


Figure 3: Number of players per level

follows and computing the arithmetic mean normally:

Strongly Agree → 2; Agree → 1; Neutral → 0; Disagree → -1; Strongly Disagree → -2

These data are evidence that the game is relatively engaging and that players perceived themselves getting better at object-oriented programming by playing the game. On the other hand, these results may be partially due to the Hawthorne effect.

The ninth and final question was free response and asked for any general comments on the game. Overall, players responded positively. Not all left feedback; many pointed out minor issues with usability and the interface, such as the relatively slow animation speed, unclear directions, and lack of examples.

We also evaluated some players in person. One interesting behavior that we observed occurred when method definitions faded from a block editor to a text editor. Some players who had trouble recalling the exact syntax returned to the other methods that were still in block-editor mode. They used the blocks, whose text had already faded into python code, as references for the new method that they wanted to type. Given that we did not tell the players about concreteness fading, this is perhaps evidence that concreteness fading can be effectively applied to programming games, and also that it was a good choice to make the fading as granular as possible. However, players also said that they wished the interface allowed them to more easily use the technique just discussed. Thus, a potential improvement is to make example blocks or example code more accessible when in the text-editor mode.

We started with 57 players who completed the pre-test, but only 12 who completed the post-test (see Figure 3). As discussed, we worked individually with all of these players, asking them to complete the game. We also captured when each player started and ended each level. This gives us a lower bound on the time spent to complete a playthrough, as the end-of-level event was not always recorded. The mean completion time was 7196 seconds, or almost exactly two hours. Figure 4 shows the mean completion time per level. However, the standard error (unshown) is very high, and the raw data looked suspect (e.g. one user completed level 10, the method overriding level, in only 47 seconds). Thus, the figures here should be taken with a grain of salt. The number of tries per level (see Figure 5) followed expectations: initial levels

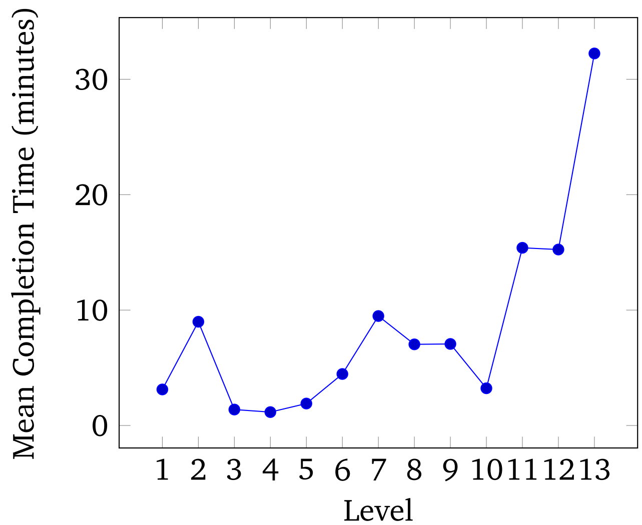


Figure 4: Mean level completion times, in minutes

required only a few tries, and later levels took more tries, with the number varying more by player.

5 Conclusions

Although we should keep in mind the issues with the design of the test, we did demonstrate a statistically significant improvement in test scores. Furthermore, the fact that the players were able to complete the game meant that their skills transferred from manipulating blocks to writing code. Indeed, as the anecdote above demonstrates, some players used the blocks to help them with Python syntax! Thus, our idea of combining visual programming and concreteness fading was able to successfully teach instantiation, based on the comparison of which questions improved between pre-test and post-test. Overriding did not seem to be reinforced.

However, it should be noted that we had to individually work with all testers who completed the test. We did this because of time constraints in finding test subjects, but it does skew the subjective enjoyment of the game, in that those who never completed it did not report their impressions.

5.1 Future Work

The current game only implements a few object-oriented features, and does not try to tackle the more complex ones, such as polymorphism. And while the expressiveness of the block language was purposely limited to simplify levels, being able to use parameters, define subclasses, and more would enable us to cover more object-oriented concepts. As discussed previously, we would also like to improve our testing methodology to account for biases and mistakes in the test design.

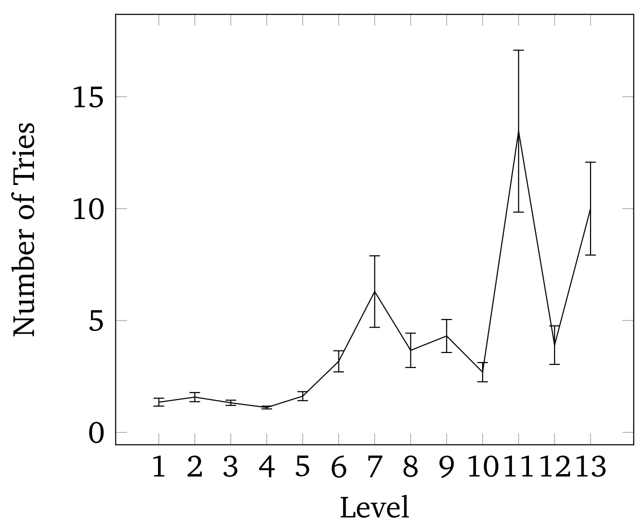


Figure 5: Mean number of tries per level