Adapting Higher-order List Operators for Blocks Programming

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***Abstract*—In MIT App Inventor (AI), puzzle-shaped blocks are connected to program Android apps. AI has Python-like lists typically manipulated with loops, but implementing such loops correctly is challenging for novice AI programmers. To simplify list processing, we extended AI with new blocks that map, filter, reduce and sort lists. Since AI does not have first-class functions, these pseudo-higher-order list operator (PHOLO) blocks incorporate the parameter and body declarations of functional arguments normally associated with these operators. To assess the usability of these new list operators, we conducted a user study with 18 students with AI experience. Most users correctly completed a majority of the tasks, but many struggled with processing lists of lists and sorting tasks involving two keys.**

I. Introduction

Blocks programming languages, in which program syntax trees are represented as compositions of visual puzzle-shaped blocks, are increasingly used in introductory programming environments. Tens of millions of people of all ages and backgrounds have programmed in blocks-based environments, which include Scratch ([1], [2]), Blockly [3], Snap! [4], Pencil Code [5], and Code.org's *Hour of Code* exercises [6]. Our focus in this paper is MIT App Inventor (AI) [7], in which a blocks language is used to specify the behavior of components in a mobile app for Android devices.

AI's only data structure is a Python-like list, an indexed sequence of mutable slots, each of which contains an item. AI lists are often processed using loops that iterate over the items or indices of the list. There are three looping blocks in AI: a `for each item` loop that iterates over each item in a list (see Fig. 1); a `for each number` loop that iterates over a range of numbers; and a `while` loop that iterates until its test expression becomes false.

In our experience, AI beginners frequently have trouble correctly processing lists with loops. For example, in a CS0 mobile apps course taught by Turbak using AI in Fall, 2014 [8], 9 of 20 apps for the final two projects had at least one incorrectly defined loop. All 9 failed to properly initialize a global variable in at least one loop. In the context of Fig. 1, this bug would be failing to include the block that sets the global variable `filteredPhrases` to the empty list at the beginning of the `Click` event handler. Because this global variable is initialized to the empty list when it is declared at top level, the handler will work the first time the button is clicked, but not subsequent times. There were other loop troubles as well, such as index-out-of-bounds errors, and unnecessarily complex loops that used a `for each number` loop to select list items by their indices instead of the simpler `for each item` loop to iterate over the items directly.

Can such problems be mitigated by discouraging the use of global variables? AI programs can sometimes be restructured to replace global variables by local ones, but the event-based nature of AI programming forces many variables to be global [9]. In the case of Fig. 1, if `filteredPhrases` is referenced by other event handlers in the game, it must remain global.

Many AI blocks encapsulate high-level, easy-to-use abstractions that hide many low-level complexities. Keeping with this philosophy, we decided to address common problems with loop-based list processing by providing new high-level list-processing blocks (`map`, `filter`, `reduce`, and `sort`) that capture common looping patterns. These were inspired by similar list operators in functional languages (e.g., Scheme/Racket, Haskell, ML), as well as in Python and JavaScript.

Functions like map, filter, reduce, and sort are known as **higher-order list operators** (which we shall abbreviate as HOLOs) because they take functions as arguments. Since AI does not currently support first-class function values, HOLOs cannot be directly added to AI. We solve this problem by creating specialized blocks we call **pseudo-higher-order list operators** (PHOLOs) that have the parameters of the usual functional arguments baked into the blocks. For example, Fig. 2 shows how the `Click` handler from Fig. 1 can be simplified with our new `filter` block, which, in addition to a list argument, has an `item` parameter that ranges over the list items and a boolean `test` expression that determines which items are kept in the new list returned by the block. Moreover, by avoiding directly initializing and appending to the global `filteredPhrases` list and instead updating it after the filtering process, we completely avoid the common pre-loop global variable initialization bug described above.

In the rest of this paper, we present the design of our PHOLO blocks and describe a study we conducted to evaluate their usability. Our contributions are (1) developing a way to express powerful HOLO-like operators using PHOLOs in a blocks language that does not support first-class functions and (2) assessing the usability of these PHOLO blocks.

II. Design of Pseudo-higher-order List Blocks

A. Map, Filter, and Reduce Blocks

Fig. 3 displays our PHOLO `map`, `filter`, and `reduce` blocks. Following AI's convention, verbose labels convey the meaning of blocks and their sockets. So what we call the `map` block is actually labeled `make new list from` *input list socket* `mapping each` *item parameter* `to` *indented body socket*. Rather than taking a function as an argument (which is

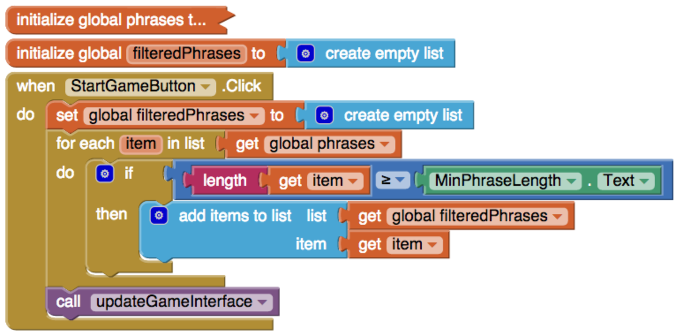

initialize global phrases t...
initialize global filteredPhrases to create empty list
when StartGameButton .Click
do set global filteredPhrases to create empty list
for each item in list get global phrases
do if length get item ≥ MinPhraseLength . Text
then add items to list list get global filteredPhrases
item get item
call updateGameInterface

Fig. 1. The `Click` handler initializes global variable `filteredPhrases` to an empty list, and then the `for each item` loop populates it by all strings in the global list `phrases` (collapsed to hide details) whose string length is at least the number specified in the `MinPhraseLength` text box. `filteredPhrases` is then used in a call to the `updateGameInterface` procedure (whose definition is not shown). As the loop executes, the loop variable `item` successively takes on the value of each list item.

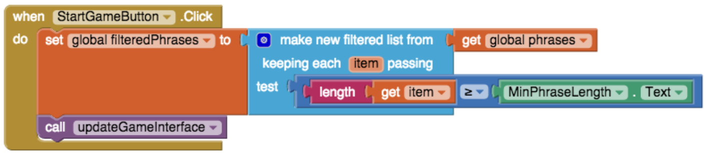

when StartGameButton .Click
do set global filteredPhrases to make new filtered list from get global phrases
keeping each item passing
test length get item ≥ MinPhraseLength . Text
call updateGameInterface

Fig. 2. The `Click` handler with our new `filter` block (labeled `make new filtered list from`). It declares a baked-in `item` parameter that ranges over all input list items and is referenced from the `test` expression.

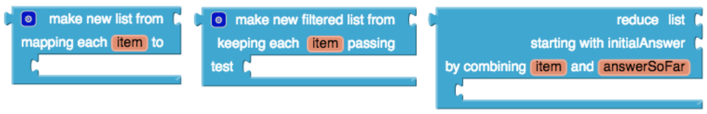

make new list from
mapping each item to
make new filtered list from
keeping each item passing
test
reduce list
starting with initialAnswer
by combining item and answerSoFar

Fig. 3. The PHOLO `map`, `filter`, and `reduce` blocks for AI.

impossible in AI), these blocks incorporate both (1) the parameter(s) of that function (as the salmon-colored parameter(s) on the block) and (2) a hole for the body of that function (the indented expression socket below the parameter). Together, these two parts play the same role as the usual functional argument for the traditional HOLO versions of these blocks. This relationship is clarified in Fig. 4, which shows a Python `map` function called on an anonymous `lambda` incrementing function and a list of numbers and how this is expressed with the AI `map` block. Note how the `item` parameter of `lambda` is incorporated into the `map` block, and the body of the `lambda` is provided as a body expression (in the scope of `item`) that fills the indented expression socket of the `map` block.

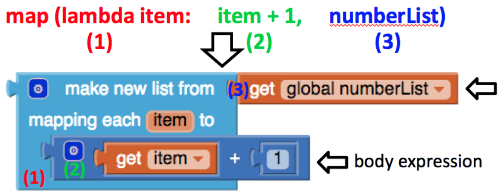


Fig. 4. The anonymous function's `item` parameter is baked into the `map` block, and its body fills `map`'s expression socket in the scope of this parameter.

Fig. 5 show a sample `map` execution using AI's *DoIt* feature, which annotates selected expression blocks with bubbles showing their values. We can tell from the *DoIt* bubble on `numberList` that it denotes a list of five numbers. Similarly, the *DoIt* bubble on the `map` block indicates that its result is a new list of five numbers where each number is one more than the corresponding number in the input list.

The `filter` block is similar to `map` and has already

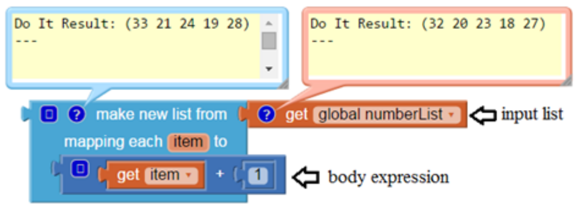
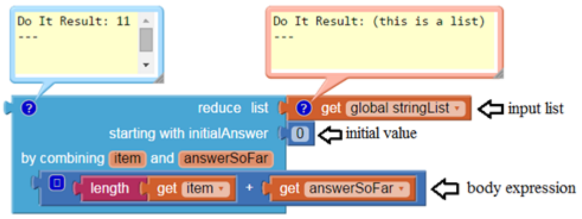


Fig. 5. *DoIt* bubbles show the dynamic behavior of the `map` example.

been explained in the context of Fig. 2. The `reduce` block (Fig. 6) combines the items of the input list into an answer value. It begins with the input `initialAnswer` (the answer when the list is empty; 0 in this example), and processes the items left-to-right, combining the current answer (named by `answerSoFar`) with the current list item (named by `item`) to produce the next answer. The combination is performed by the body expression. In the example, the input list has four strings, and the output is the sum of the lengths of these strings.


Do It Result: 11

Do It Result: (this is a list)
---
reduce list
get global stringList
input list
starting with initialAnswer 0
initial value
by combining item and answerSoFar
length get item + get answerSoFar
body expression

Fig. 6. A `reduce` block that sums the lengths of strings in its input list.

B. Sort Blocks

AI currently does not have a list sorting operator. One can be defined as an AI procedure, but this is beyond the capabilities of most beginning AI programmers. We fix this problem by providing three `sort` blocks (Fig. 7). The first, $\texttt{sort}_{basic}$, has no baked-in parameters and uses a default comparator. It returns a new list that is a sorted version of the input list, where elements are sorted in ascending order first by type and then by values within each type, using an arbitrary ordering on types and standard orderings on values.

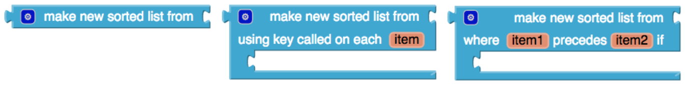
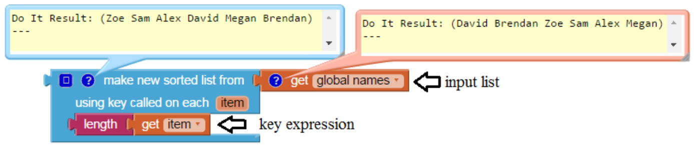

make new sorted list from
make new sorted list from
using key called on each item
make new sorted list from
where item1 precedes item2 if

Fig. 7. The $\texttt{sort}_{basic}$, $\texttt{sort}_{key}$, and $\texttt{sort}_{comp}$ blocks.

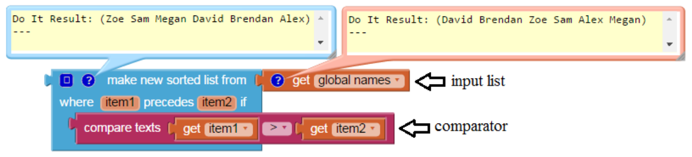
The second sort block, which we call $\texttt{sort}_{key}$, has a single `item` parameter and a socket for a body expression. Together, these determine a proxy value that is used to sort the item by the default comparator of $\texttt{sort}_{basic}$. E.g., in Fig. 8, $\texttt{sort}_{key}$ sorts a list of strings in ascending order by their lengths.


Do It Result: (Zoe Sam Alex David Megan Brendan)

Do It Result: (David Brendan Zoe Sam Alex Megan)
---
make new sorted list from
get global names
input list
using key called on each item
length get item
key expression

Fig. 8. Using $\texttt{sort}_{key}$ to sort strings by their lengths. The sort is *stable*; items with equal proxy values keep their same relative order from the input list to the output list. This is why `Zoe` appears before `Sam` in the output list.

The third sort block, $\texttt{sort}_{comp}$, has *two* parameters, `item1` and `item2`, and a socket for a boolean body expression. Together, these denote a less-than-or-equal-to comparison function. If the body expression evaluates to true, then `item1` will precede `item2` in the output list; otherwise `item2` will precede `item1`. For example, in Fig. 9, the comparator specifies that the strings should be sorted in descending lexicographic order.



```
Do It Result: (Zoe Sam Megan David Brendan Alex)
---
```

```
Do It Result: (David Brendan Zoe Sam Alex Megan)
---
```

make new sorted list from
get global names
input list
where item1 precedes item2 if
compare texts get item1 > get item2
comparator

Fig. 9. Using $\texttt{sort}_{comp}$ to sort strings in descending lexicographic order.

III. User Study

A. Purpose and Structure of the Study

To assess the usability of PHOLO blocks, Kim facilitated a user study with 18 Wellesley College students familiar with AI from a course or a project. The purpose of this study was to determine if the new list operators are usable by AI's target audience — users with limited programming background. Here we summarize key aspects of the study and its results; for details, see Kim's undergraduate dissertation [10].

Each user study lasted up to 90 minutes. Participants first filled out a pre-task survey indicating age, major(s), previous knowledge of AI and HOLOs (if any), and CS courses taken. All were women aged 18–23. They had 7 different majors, with 11 users majoring in CS or double majoring in CS and another subject. To control for skill level and background, we divided them into two groups: Group 1, the 10 students (56%) who had previously seen HOLOs in Python, OCaml, or Scheme/Racket; and Group 2, the 8 students (44%) without such exposure.

The next step was a brief tutorial on each PHOLO block, followed by a set of tasks that involved writing new programs and explaining the meaning of programs that use the PHOLO blocks. Kim took notes during each study and recorded a screencast capturing the user's voice and actions on the screen.

The first part of the study consisted of eight tasks involving mapping, filtering and/or reducing over a simple list or a list of lists. The second part of the study involved six sorting tasks on a list of lists. Users tested their programs by connecting the computer to an Android device and running *DoIt* on the blocks. The study ended with a post-task survey where users indicated why it was easy or difficult to use the PHOLO blocks and shared any suggestions for improvements.

B. Results for Mapping, Filtering, and Reducing Tasks

Fig. 10 shows the successful task completion rate for the 8 tasks involving `map`, `filter`, and `reduce`. Group 1 had an average success rate of 98% on these tasks, compared to 67% for Group 2. All Group 1 users correctly completed at least 7 of the 8 tasks. Two could not explain the meaning of a program that filtered, mapped and then reduced over a list of lists. But all Group 1 users correctly completed the synthesis task using a a combination of these blocks. In Group 2, all users successfully mapped and filtered over a simple list. But many struggled with the concept of reduction, with using any of these operators on a list of lists, and with using these operators in combination with one another.

Something not reflected in Fig. 10 is that many users who eventually correctly completed a task encountered some problems along the way. They often referred back to tutorial examples to figure out how to use the blocks correctly, especially when they encountered an error. Overall, students in

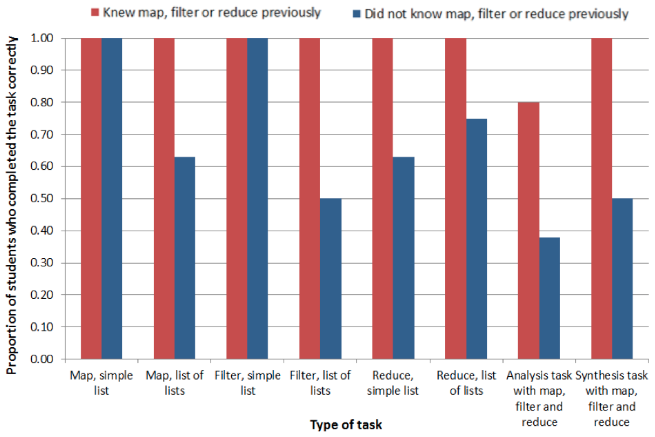


Fig. 10. Comparison of performance on the `map`, `filter`, and `reduce` portion of the study between Group 1 (ten users with previous HOLO exposure, in red) and Group 2 (eight users without HOLO exposure, in blue).

Group 1 were better at such debugging than those in Group 2, a key factor in their better performance.

Users in both groups faced two common problems. First, 6 users (60%) in Group 1 and 8 users (100%) in Group 2 had trouble selecting the correct item of each sublist when mapping, filtering, or reducing over a list of lists. In these situations, the PHOLO block implicitly selects elements from the outer list, but the user must explicitly select an element from the inner list that is bound to the block's `item` parameter. The second most common mistake (made by 6 users in each of Groups 1 and 2) was concatenating strings in the wrong order using `reduce`. The `reduce` block tutorial did not emphasize that items are processed left-to-right. This was potentially confusing to Group 1 students familiar with the right-to-left nature of OCaml's `foldr` function from Wellesley's *Programming Languages* class. Also, during the study, we realized that the parameter order (`item` before `answerSoFar`) may encourage a right-to-left interpretation and is the opposite order of the combiner function parameters for Python's `reduce` operator, which some students might have known. For these reasons, we plan to swap the order of these parameters in the future.

In the post-task survey, many users commented that the brief tutorial and simple examples of each block were helpful. Group 1 students said they felt comfortable using the PHOLO blocks because of their previous HOLO experience. For Group 2 students, a key source of difficulty was keeping track of the functionality of each PHOLO block and the differences between them. However, they found the labels on the blocks helpful for remembering how these block should be used.

C. Results for Sorting Tasks

For the six sorting tasks, Fig. 11 shows that Group 1 again performed just as well or better than Group 2 on all the tasks.

Overall, the results show that a large majority of users in both groups were able to sort the given list in ascending or descending order by the element itself or by one key. However, sorting with two keys proved particularly challenging. This was in part due to flaws in the study involving unexplained subtleties of the stability of the sorting algorithm as well as the particular list being sorted; see [10] for details.

There were two common problems encountered during the sorting tasks. First, when using $\texttt{sort}_{comp}$, a total of nine users

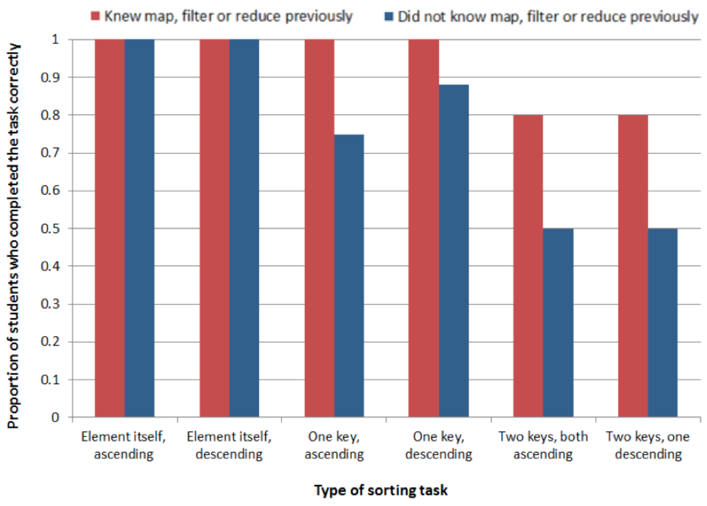


Fig. 11. Comparison of Group 1 and Group 2 on the sorting tasks.

(50%) tried to use the boolean test `item1 > item2` to sort the list in increasing order or the test `item1 < item2` to sort the list in decreasing order. Six users (60%) in Group 1 and three users (38%) in Group 2 made this mistake. We thought that the English phrasing "where `item1` precedes `item2` if" on the $\texttt{sort}_{comp}$ block would strongly suggest the correct interpretation, but the results say otherwise. The second confusion was experienced by three users in each of Group 1 and Group 2: trying to use $\texttt{sort}_{key}$ (which sorts in increasing order only) for tasks that required sorting in decreasing order. These problems indicate that the `sort` blocks need to be better explained in documentation and tutorials.

In the post-task survey, most users indicated that they found $\texttt{sort}_{basic}$ and $\texttt{sort}_{comp}$ intuitive to use. Several, however, said they did not understand how and when to use $\texttt{sort}_{key}$ and asked for more examples involving keys. Others did not like having to choose between $\texttt{sort}_{key}$ and $\texttt{sort}_{comp}$. Since $\texttt{sort}_{comp}$ can do everything that $\texttt{sort}_{key}$ does (and more), we plan to eliminate $\texttt{sort}_{key}$ going forward.

IV. Related Work

Like AI, several other blocks languages with list or array-like data structures, including Scratch [1] and StarLogo Nova [11], do not have HOLOs, so users use loops with list indexing to iterate through list elements. A notable exception is Snap! [4], a blocks language based on Scratch that supports Scheme-like higher-order functions (HOFs), including list mapping, filtering, and reducing blocks. In the Snap! mapping example in Fig. 12, the multiplication block with an empty input surrounded by a gray ring denotes a one-argument doubling function. The gray ring wrapper is a concise visual notation for declaring an anonymous function [12].

The Droplet editor ([13], [14]) for Pencil Code [5] and Code.org's App Lab supports isomorphic conversions between the textual notations of existing languages and a blocks notation. When it is used for languages with anonymous first-class function declarations, like dialects of JavaScript, the shapes of the resulting function blocks resemble gerrymandered districts (Fig. 13). Just as AI avoids the complexity of first-class function callbacks in programs like Fig. 13 with its top-level parameterized event handlers [9], PHOLO blocks similarly avoid the complexity of blocks for functional arguments.

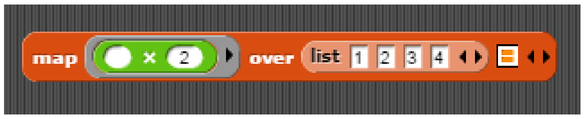
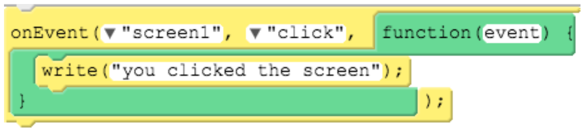


Fig. 12. Mapping example in Snap!



```
onEvent("screen1", "click", function(event) {
  write("you clicked the screen");
});
```

Fig. 13. The green block is a function declaration block in the Droplet editor for Code.org's App Lab.

A key advantage of PHOLOs vs. HOLOs is that PHOLOs avoid conceptual difficulties with HOFs observed in [15], [16]. For many years, Turbak has introduced `map`, `filter`, and `reduce` in courses via examples with explicit anonymous function (as opposed to named function) arguments so that the function parameter names are explicit. PHOLO blocks are a visual embodiment of this pedagogical strategy.

Numerous older visual languages support higher-order operators on lists and arrays. Most of these are dataflow languages. In Show and Tell [17], iteration boxes with so-called parallel ports allow processing of individual array elements. LabView's tunneling and auto-indexing features similarly allow processing array elements in loops [18]. Both Extended Show And Tell [19] and DataVis [20] extend Show and Tell with means of passing and applying HOFs. Prograph's list annotations enable specifying code that is run on each element of a list, and its inject feature allows specifying a function argument by name [21]. VPL [22] and VisaVis [23] are dataflow systems for functional programming with an emphasis on HOFs. Tonic [24] uses a dataflow visualization with support for HOFs to specify reactive web-based multi-user applications. One non-dataflow language in this category is CUBE ([25], [26]) a three-dimensional visual logic programming language that can express HOLOs like `filter`. We know of no studies evaluating the usability of HOLO features in these languages.

V. Conclusion and Future Work

We have implemented our PHOLO blocks in an experimental version of AI, and it is being reviewed for integration into the master version. Although beginners can use them in some situations, our user study indicates that more work needs to be done to make these operators less confusing to those who have not previously seen similar operators. In addition to improving documentation and tutorials, we need to carefully finalize the labels and parameter names on PHOLO blocks. We have recently learned about the syntactic choices made in the evidence-based programming language Quorum ([27]) and wonder if a similar methodology could be applied here.

In our user study, we only tested the usability of PHOLO blocks and did not test whether list processing with these blocks is easier or harder than with loops. We plan to conduct a user study to investigate this, and aim for this study to have a wider demographic base (in terms of age, gender, and background) than the one reported here.

Acknowledgments

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References

[1] Scratch project, MIT Lifelong Kindergarten Group, http://scratch.mit.edu/, accessed Sep. 4, 2015.

[2] J. Maloney, M. Resnick, N. Rusk, B. Silverman, and E. Eastmond, "The Scratch programming language and environment," *ACM Transactions on Computing Education*, vol. 10, no. 4, Nov. 2010.

[3] Neil Fraser, Blockly website, https://developers.google.com/blockly/, accessed Sep. 4, 2015.

[4] B. Harvey and J. Mönig, "SNAP! 4.0 reference manual," https://snap.berkeley.edu/SnapManual.pdf, accessed Sep. 4, 2015.

[5] D. Bau, D. A. Bau, M. Dawson, and C. S. Pickens, "Pencil Code: Block code for a text world," in *Proceedings of the 14th International Conference on Interaction Design and Children*, ser. IDC '15, 2015, pp. 445–448.

[6] Code.org, Hour of Code website, http://code.org/learn, accessed Sep. 4, 2015.

[7] MIT Center for Mobile Learning, MIT App Inventor website, http://appinventor.mit.edu, accessed Sep. 4, 2015.

[8] F. Turbak, "CS117: Inventing Mobile Apps," Wellesley College course, Fall 2014 semester. Course website: https://sites.google.com/a/wellesley.edu/wellesley-cs117-fall14, accessed Sep. 4, 2015.

[9] F. Turbak, M. Sherman, F. Martin, D. Wolber, and S. C. Pokress, "Events-first programming in App Inventor," *Journal of Computing Sciences in Colleges*, Apr. 2014.

[10] S. Kim, "Developing and assessing new list operators in App Inventor," undergraduate thesis, Wellesley College, May, 2015. Available at http://repository.wellesley.edu/thesiscollection/247.

[11] StarLogo Nova project, MIT Scheller Teacher Education Program, http://www.slnova.org, accessed Sep. 4, 2015.

[12] B. Harvey and J. Mönig, "Lambda in blocks languages: Lessons learned," in *IEEE Blocks and Beyond Workshop*, 2015, to appear.

[13] D. A. Bau, "Droplet, a blocks-based editor for text code," *Journal of Computing Sciences in Colleges*, vol. 30, no. 6, pp. 138–144, Jun. 2015.

[14] ——, "Integrating droplet into Applab — improving the usability of a blocks-based text editor," in *IEEE Blocks and Beyond Workshop*, 2015, to appear.

[15] M. Eisenberg, M. Resnick, and F. Turbak, "Understanding procedures as objects," in *Empirical Study of Programmers: Second Workshop*, G. M. Olson, S. Sheppard, and E. Soloway, Eds. Ablex, 1987, pp. 14–32.

[16] J. DiBiase, "Challenging students' misconceptions of higher-order mathematics: Visualizing functions as data objects," Institute of Cognitive Science, Department of Computer Science, University of Colorado, Tech. Rep. TR 95-07, Jul. 1995.

[17] T. D. Kimura, J. W. Choi, and J. M. Mack, "A visual language for keyboardless programming," Department of Computer Science, Washington University, St. Louis, Tech. Rep. TR WUCS-86-6, Jun. 1986.

[18] R. Bitter, T. Mohiuddin, and M. Nawrocki, *LabView: Advanced Programming Techniques (2nd ed.)*. CRC Press, 2006.

[19] M. A. Najork and E. Golin, "Enhancing Show-and-Tell with a polymorphic type system and higher-order functions," in *IEEE Workshop on Visual Languages*, 1990, pp. 215–220.

[20] D. D. Hils, "DataVis: A visual programming language for scientific visualization," in *Proceedings of the 19th Annual Conference on Computer Science (CSC '91)*, 1991, pp. 439–448.

[21] "Prograph CPX – A Tutorial," *MacTech*, vol. 10, no. 11, 1994.

[22] D. Lau-Kee, A. Billyard, R. Faichney, Y. Kozato, P. Otto, M. Smith, and I. Wilkinson, "VPL: an active, declarative visual programming system," in *IEEE Workshop on Visual Languages*, 1991.

[23] J. Poswig, G. Vrankar, and C. Moraga, "VisaVis: a higher-order functional visual programming language," *Journal of Visual Languages and Computing*, vol. 5, pp. 83–111, Mar. 1994.

[24] J. Stutterheim, R. Plasmeijer, and P. Achten, "Tonic: An infrastructure to graphically represent the definition and behaviour of tasks," in *Trends in Functional Programming: 15th International Symposium, TFP 2014, Revised Selected Papers (LNCS 8843)*. Springer, 2015, pp. 122–141.

[25] M. A. Najork and S. M. Kaplan, "The CUBE language," in *7th IEEE Workshop on Visual Languages*, 1991.

[26] M.-A. Najork, "Programming in three dimensions," Ph.D. dissertation, University of Illinois, Urbana-Champaign, 1994.

[27] A. Stefik, S. Siebert, M. Stefik, and K. Slattery, "An empirical comparison of the accuracy rates of novices using the quorum, perl, and randomo programming languages," in *Proceedings of the 3rd ACM SIGPLAN Workshop on Evaluation and Usability of Programming Languages and Tools*, ser. PLATEAU '11, 2011, pp. 3–8.