Design and Evaluation of a Block-based Environment with a Data Science Context

Austin Cory Bart, *Member, IEEE,* Javier Tibau, *Member, IEEE,* Dennis Kafura, *Member, IEEE,* Clifford A. Shaffer, *Senior Member, IEEE,* and Eli Tilevich, *Senior Member, IEEE*

Abstract—As computing becomes pervasive across fields, introductory computing curricula needs new tools to motivate and educate the influx of learners with little prior background and divergent goals. We seek to improve curriculum by enriching it with authentic, real-world contexts and powerful scaffolds that can guide learners to success using automated tools, thereby reducing the strain on limited human instructional resources. To address these issues, we have created the BlockPy programming environment, a web-based, open-access, open-source platform for introductory computing students (https://www.blockpy.com). BlockPy has an embedded data science context that allows learners to connect the educational content with real-world scenarios through meaningful problems. The environment is block-based and gives guiding feedback to learners as they complete problems, but also mediates transfer to more sophisticated programming environments by supporting bidirectional, seamless transitions between block and text programming. Although it can be used as a stand-alone application, the environment has first-class support for the latest Learning Tools Interoperability standards, so that instructors can embed the environment directly within their Learning Management System. In this paper, we describe interesting design issues that we encountered during the development of BlockPy, an evaluation of the environment from fine-grained logs, and our future plans for the environment.

Index Terms—Computer Science Education, Introductory Computing, Block-based Programming, Data Science, Automatic Guidance.

1 Introduction

As computing has become pervasive across careers and disciplines, there is a growing population of students and professionals alike seeking to develop computational skills and thought processes [1]. Efforts to address their needs include general education curricula in higher and secondary education (e.g., "Computational Thinking" and "Computer Science Principles" courses) [1], [2], Massive Open Online Courses [3], and even individualized, informal learning platforms (e.g., CodeCademy) [4]. Because these learners have dissimilar motivations, clarity of goals, and depth of prior experiences [5], [6], they need support from specialized educational approaches, as compared to traditional Computer Science students [7], [8].

We seek to support these learners by means of BlockPy, a web-based, open-source, introductory programming environment (https://www.blockpy.com), emphasizing data science as an authentic learning context. By an authentic context, we mean that learners perceive a connection to a real-world community of practice that is relevant to their long-term goals. The environment provides scaffolds through a dual text/block interface and guiding feedback, making it well-suited for introductory computing students, particularly non-majors.

The intended audience of the paper is educators interested in using BlockPy and developers who would wish to develop systems similar to BlockPy. This paper makes a number of design contributions.

1) A scaffolded, web-based environment for novice programmers,
2) Integration of authentic, real-world data sets into the environment, and
3) A feedback authoring API and an abstract interpreter for static analysis

The paper makes further contributions to evaluate the system in a real-world classroom environment, with the following results:

1) Most, but not all, of the features in the scaffolded learning environment are effective,
2) Novice learners can successfully solve data science problems within the environment, and
3) Improved guiding feedback for students is needed.

- *Computer Science, College of Engineering, Virginia Tech, Blacksburg, VA, USA.*
  Corresponding Author: Austin Cory Bart (acbart@vt.edu)
- *This material is based upon work supported by a grant from the National Science Foundation Graduate Research Fellowship, Grant No. DGE 0822220, NSF DUE 1444094, and NSF IUSE 1624320.*

Manuscript received May 1, 2015.

2 THE *Why* OF BLOCKPY

BlockPy draws inspiration from a number of theoretical and concrete sources. Design decisions were influenced by educational theories, existing introductory programming environments, and the wider community of professional software developers.

2.1 Python and Blocks

BlockPy, as its name suggests, is a block-based editor for the Python programming language. Python is a popular introductory language because of its beginner-friendly syntax, powerful library, and popularity among professional programmers [9]. So not only are learners likely to be successful when working with Python, but they can quickly enter into an authentic community of practice and start solving real-world problems. Python also has a well-earned reputation as a useful language for performing data science [10], ensuring a harmonious relationship between BlockPy's language and context, described in Section 2.2.

Block-based languages have proven themselves as a powerful scaffold for novice learners, decreasing their start-up time and helping them accomplish tasks that they originally could not [11], [12]. Blocks help beginners navigate their program's structure while preventing syntax errors. They can also visually and clearly expose a complex API, such as those used in game development or data processing. These benefits offset a major disadvantage of blocks: learners can negatively perceive block interfaces as being only for younger learners or unsuitable for professionals [13].

BlockPy has much in common with other block-based programming environments. For example, Scratch and its successor Snap! [14] largely target young learners, both in design and with their game development context. Extensions to Snap! have integrated more sophisticated program features, although these have been limited. Hellman [15] incorporated data science features, including access to real-time datasets, user-created data sources, and cloud-based data manipulation. The NetsBlox project [16] exposes distributed computing concepts by introducing event blocks for network transmissions. Others have promoted patterns for parallel programming abstractions within Snap!, such as producer-consumer and MapReduce [17].

BlockPy's emphasis on authenticity is similar to that of GP, the "The Extensible Portable General Purpose Block Language for Casual Programmers", which seeks to support more ambitious application development. Developed by members of the Scratch team, GP shared many of its design principles, including the concept of a strong social community and a blocks-first interface. A unique aspect of GP is that its development environment and module system is extensible with its own internal block-based language. The GP project attempts to establish authenticity by supporting real-world features and projects that "scale up" [18]. A potential criticism of this approach to authenticity is that, instead of a using an existing popular language, they use a language descended from Squeak.

BlockPy has much in common with other modern block-based editors for mainstream languages. PencilCode is a JavaScript editor that offers a seamless transition between blocks and text [19]. GreenFoot is a visual programming environment for creating games and animations in Java, with an innovative structured code editing interface they refer to as "Frames" [20]. Hence, supporting a dual-interface between both blocks and text is a clear trend in modern editors as a mean of transitioning students gracefully.

BlockPy is not the first web-based Python execution environment, but it advances the state-of-the-art established by its predecessors, including Pythy [21], CodeSkulptor [22], and the Online Python Tutor [23]. None of these systems support a dual block/text interface. Both CodeSkulptor and Pythy are built on the same underlying engine, Skulpt [24], which can cross-compile Python code to JavaScript. CodeSkulptor has an extensive but custom API for creating user interfaces and games, which is powerful but limits students' ability to transfer code away from the browser. CodeSkulptor is intended as an undirected environment for creativity, but therefore does not guide learners through a curriculum. Pythy, on the other hand, is an assignment-oriented application with limited support for guidance through unit testing. Pythy appears to no longer be under active development, and uses an out-of-date fork of Skulpt.

The Online Python Tutor uses remote code execution to provide visualizations of users' algorithms. Although rigorous and detailed, the OPT is not ideal for learners who must parse the complicated terminology being used. Further, the Online Python Tutor is an undirected environment like CodeSkulptor, rather than a platform for a curriculum. Finally, its dependency on a remote server makes the platform vulnerable to poor internet connections and complicates the applications' architecture.

In addition to its dual text/block interface, BlockPy also provides guided feedback. Surprisingly few introductory environments are designed to give interactive and guiding feedback to students as they run their code, usually at best relying on unit tests. CodeCademy is perhaps the most popular and successful guided platform. Unfortunately, CodeCademy is closed-source and has not published information about the efficacy of its curriculum or its techniques.

2.2 Data Science as an Authentic Context

The design of BlockPy was influenced by two educational theories, both of which stress the importance of a learning experience that students can connect to the real world. The first theory is the MUSIC Model of Academic Motivation [25]. This meta-descriptive theory, which aggregates other motivational theories, draws a distinction between students' perception of Usefulness (a sense that the material is connected to long-term goals) and Interest (a sense of intrigue and inspiration). Appealing to a student's sense of usefulness or interest is argued to strengthen their motivation, not only to complete individual assignments, but to engage with computing and understand its role in their long-term career and life goals [5]. The second theory is Situated Learning Theory. This theory describes how learners become engaged with material when they can perceive its authenticity and connection to a community of practice that they might reasonably become a part of [26]. The theory distinguishes between the content (the material to be learned), the scaffolds (the artificial additions to the environment to simplify the students' experience), and the context (the framing story used to anchor the experience). A context is authentic when the problems, practices, tools, artifacts, and/or results that students work with in their learning reflect real-world entities described by authoritative sources in a community of practice.

Many introductory computing contexts focus on invoking student interest, without providing a sense of usefulness or authenticity. Media Computation, for instance, is a creativity-based curriculum by Guzdial et al. where students create artwork and music. Although there is established motivational value in this approach [27], an analysis by Guzdial in the light of Situated Learning Theory suggested that, despite extensive efforts by course staff, students did not perceive the context as authentic or useful [28], in part because students did not perceive the context to align with a visible community of practice. Game Design is another alternative context that does have a visible community, but probably not many of these students seek to join that community as part of their career plans. We do not believe that all introductory programming environments must be authentic and focus on usefulness. For very young learners, appealing to their sense of play or story-telling might be more appropriate. We do believe that for our learners (university non-majors), authenticity and usefulness are critical.

BlockPy is part of a growing movement within computer science education to promote "data science" as an authentic context appealing to the usefulness of students in any discipline or career path. The argument is that every job and major, from the sciences to the humanities to the arts, can benefit from the ability to solve problems from a data-oriented computational perspective. Data science is authentic because 1) the data is from authoritative sources, 2) there is a real-world community of practice for data science, and 3) students can more readily see how the material connects to their long-term career goals. There are several prior data science curricula. Anderson et al. suggested a curriculum built around real-world projects and data sources [29]. Goldweber et al. [7] developed an entire framework for evaluating and designing projects with this theme. The BRIDGES project [30] has a similar goal to the CORGIS project, but is targeted at upper-level Data Structures and Algorithms courses, and has a stronger emphasis on data visualization and exploration.

BlockPy facilitates a data science context, and provides tools for students to rapidly begin working with real-world datasets relevant to their personal and work interests. Note that BlockPy, as a programming environment, does not provide a sense of authenticity. Instead, it facilitates a context that does. The computing curriculum and pedagogical decisions surrounding BlockPy are heavily influenced by this context. Lessons are built around collection-based iteration, for instance, as opposed to conditional iteration, which more naturally connects to working with collections of real-world data. Tools are also provided by the environment for conveniently visualizing and manipulating data. BlockPy is designed as an active learning environment, with an emphasis on students interacting and receiving feedback. This means that BlockPy is designed to require minimal amounts of instruction and presentation of material. At the same time, a major theme of BlockPy is scaffolding—pedagogical and technological support that enables the learner to accomplish tasks they normally would be unable to achieve. As the learner becomes more capable, the scaffolding fades away.

The authors have had prior success in using a data science context through the CORGIS project, which makes it easier to introduce real-world datasets into an introductory computing curriculum in order to motivate students. This project has been deployed in a college-level Computational Thinking course, with great effect on student motivation [31], [32]. This paper does not further evaluate the data science context, but focuses instead on the scaffolds developed for the environment.

3 *BlockPy*'s Major Features

In this section, we briefly describe the major features of BlockPy. An overview of the web-based interface is shown in Figure 1. At a high level, the left side of the interface is the editor, and the right side is where

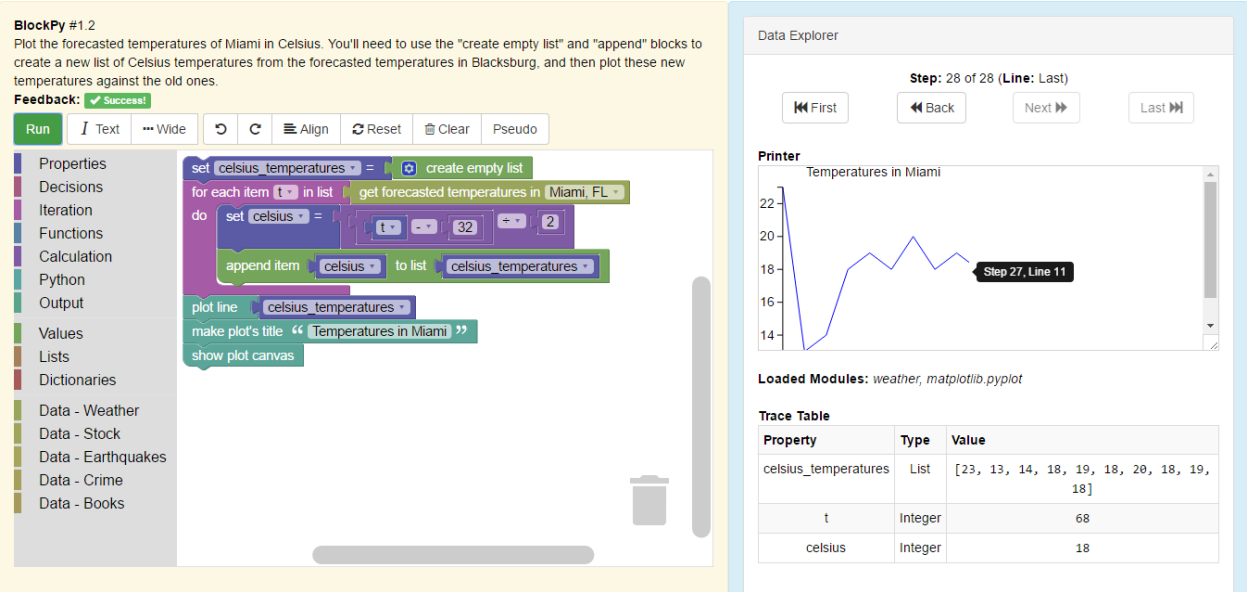


Fig. 1. A Screenshot of BlockPy in Action

code execution is visualized. The goal of BlockPy is to make itself unnecessary, and graduate the learner into a professional programming environment. Scaffolding eases this transition and, where possible, the environment attempts to maintain an authentic programming experience. Figure 1 shows the version of BlockPy used in the associated study, while recent versions change some of the layout.

Dual Block/Text Modes One of the most visible features of BlockPy is its dual text/block interface. At any time, users can switch between a block or a text representation of their code, as shown in Figure 2. The block interface uses the Google Blockly library [33], while the text interface uses the CodeMirror library [34]. The Blockly library has been extended with a number of new blocks and features to connect more gracefully with the Skulpt execution engine. In particular, Skulpt parse trees can be converted into Blockly parse trees.

Guided Feedback Although the block interface is a useful mechanism for introductory programmers to avoid syntax errors, the most valuable pedagogical component of BlockPy is its Guided Feedback system. Through a custom interface, instructors can define a function that takes the student's code, a trace of its execution, and any output; the function can then return either HTML feedback or an indication that they have successfully completed the problem. BlockPy is therefore able to give many kinds of guidance, controllable by the instructor: suggestions on what is wrong, hints on what to fix, specific instructions to seek further help, or even complimentary feedback. For example, in a problem where students must sum a list of integers representing temperatures, the instructor can write feedback code to detect the presence of a `FOR` loop in the code—if it is not present, then a message could be displayed suggesting they need to read a chapter about Iteration. BlockPy's regular error messages have been extended with additional information for beginners.

Python Execution Environment BlockPy uses the Skulpt engine to execute Python code entirely within the users' browser. Skulpt works as a "transpiler", or source-to-source compiler. It parses a string of valid Python source code into an Abstract Syntax Tree represented as a JSON-encoded object. A symbol table is constructed, and then a JavaScript execution engine interprets the AST. No bytecode is created, and the JavaScript is executed within the client's browser. Skulpt uses suspensions so that code execution is a non-blocking activity.

The biggest advantage of this approach is that code can be executed much faster since there is no round trip to a server. Students can continue to work even without an Internet connection. Complicated sandboxes are not necessary for running the student's code, since they are limited to the API exposed by their browser. In fact, Skulpt even protects the client's environment, since the Window namespace is unexposed (except through explicit APIs, discussed in a later section).

Natural Language Code Description Another scaffold of BlockPy is a natural language program description generator. Conventionally, written code is parsed into an Abstract Syntax Tree. In BlockPy, the transition occurs in the other direction—an AST is used to gen-

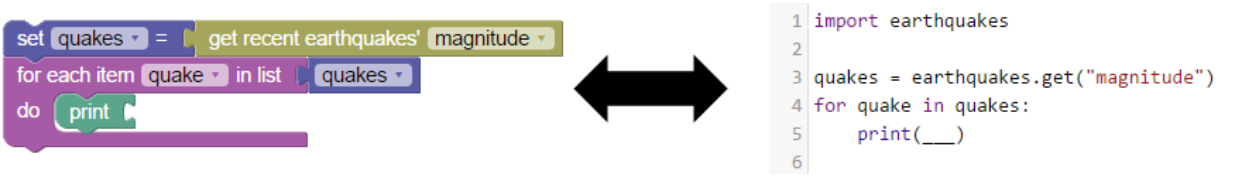


Fig. 2. Mutual Language Translation between Block and Text interfaces

erate a string of conventional English text. It can be seen as a third phase to the existing dual text/block mode, although it does not support editing, being a one-way transition. The goal of this code explanation is for students to better understand the meaning of their code. Obtuse language features can be translated into more meaningful statements.

Property Explorer After a program is run, BlockPy supports traversal of the executions' trace. We have found through classroom observations that introductory students often struggle to trace the execution of their programs on their own. Using the property explorer, not only can students observe the appearance and value of their variables, but also their type. Further, they can "rewind" print and plot operations to observe the impact of these statements.

CORGIS Integration BlockPy promotes a data science learning context. To achieve this, BlockPy natively integrates CORGIS, the Collection of Real-time, Giant, Interesting dataSets. CORGIS contains diverse data, from authoritative sources. The subset of CORGIS exposed in the current BlockPy interface is selected based on perceived popular appeal, simplicity, and pedagogical affordances of the data. These libraries are available through simple blocks. These blocks translate into function calls that return structured data at varying levels of complexity depending on the block chosen (e.g., `get_temperature` returns a single integer, `get_temperatures` returns a list of integers, `get_forecasts` returns a list of dictionaries with integers and strings, etc). Figures 1 and 2 demonstrate these blocks in action.

Plotting Another addition to Skulpt is tools for making visualizations, a core activity for data science. Currently, BlockPy supports the creation of line plots, scatter plots, and histograms. We build on prior work to support these within Skulpt, using an API identical to the popular MatPlotLib API [35]. By mimicking this professional API, BlockPy increases its authenticity and promotes transfer.

LTI Support Although BlockPy has its own internal course management system, it also supports LTI (Learning Technology Interoperability). This important standard separates "Tool Consumers" from "Tool Providers". That is, it provides a mechanism for Learning Management Systems (e.g., Canvas, Sakai, Blackboard, Moodle) to interact with external tools. Instructors who have configured BlockPy to work with their LMS can select, create, and edit assignments all from within their LMS of choice. When students complete problems in the BlockPy environment, they are automatically graded, and the LMS is given the relevant information.

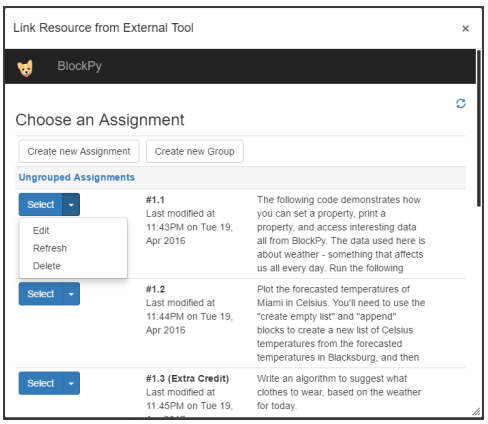


Fig. 3. Course Assignment Management

LTI supports user authentication through Canvas (and potentially other LMS). When a student loads a BlockPy problem, Canvas delivers their email address to BlockPy. This information is used to determine if an account exists for that student. If it does not, they are introduced to the system and vouched for by the LMS.

To support the LTI standard, we have started work on spinning off a template for future Python-based LTI applications. This open-source project is available at https://github.com/acbart/lti-flask-skeleton.

4 Design Issues

We next present design issues that were addressed when developing BlockPy. These issues should be of interest to developers of other introductory environments.

4.1 Internal Code Representation

Dual block/text editors create an added challenge in deciding the right internal representation of the students' code. BlockPy uses the textual version as the canonical representation, as opposed to the block parse tree. However, there were other options. Some editors operate on Parse Trees exclusively. Others treat

```
import stocks

stocks = stocks.get_past("FB")
new = []
for stock in new:
    new = []
for stocks in stocks:
    print(stocks)
```

Fig. 4. Degenerate Student Code

the source code as a list of lines (separating elements by the newline), sometimes attaching special properties to individual lines such as geometric information [19]. A major limitation of both representations is that some valuable programmer-level semantic data is not preserved. On the text side, user-created whitespace does not survive the transition. On the block side, block layouts are reset according to the default rules. The original dual text/block editor created by Mastuwaza [36] solved this problem by storing geometric information of blocks in the comments of the text mode. However, this leads to crowded code with confusing comments. The trade-offs in this system led to BlockPy's design as a primarily text-driven environment under the hood.

4.2 Block Language

A criticism of the block interface is that the blocks do not use accurate Python syntax. For example, the collection iteration block that models a Python `For ... in` loop has more explicit plain text phrasing, to explain the nature of the block more clearly: `for each item [__] in list [__]`. Similarly, the assignment block has the text `set [__] = [__]`. Over time, BlockPy's exact wording has evolved to more closely match Python. However, we feel that explicit text is more helpful to beginners. Although there are advantages to more understandable blocks, there are credible concerns that beginners may learn incorrect syntax.

4.3 Parser Errors vs. Syntax Errors

In theory, it is impossible to generate syntactically incorrect Python code when transitioning from the blocks to text. However, it is quite possible for students to write invalid code from the text editor, making the transition back to blocks problematic. A missing colon, unclosed parentheses, or incorrect indentation will prevent Skulpt from generating a valid parse tree. When encountering code with a syntax error, BlockPy creates "raw blocks" that store the literal Python code. BlockPy will also create raw blocks for language features that are not implemented in the block interface, but most of these features are uncommon, such as `else` bodies in `for` loops.

The algorithm for translating code attempts to create as many blocks as possible, but can often be confounded into creating one large raw block. Although some might consider this a major disadvantage, it is not necessarily desirable to ensure that students are always writing completely valid programs at all times, especially in the early stages of constructing an algorithm, particularly when new programming constructs are introduced. Although BlockPy is built on the premise that it is worth delaying the conversation about syntax, all students must eventually become comfortable with the details of writing structurally correct code.

It is not always possible to automatically correct a students' written code to match their intent. (Sometimes students may not even understand their own intent!) However, there are more sophisticated approaches to improving the support given to students. A more robust parser could be developed to precisely identify student code errors. Alternatively, every subset of the code could be parsed in isolation in order to determine what areas of the code are correct. Rivers and Koedinger explore other approaches that uses prior student submissions for each problem to suggest corrections to the user [37].

TABLE 1
Overview of the BlockPy Curriculum

Problems	Type	Topics
#1.1-#1.5	Classwork	Printing, Variables, Plotting
#1.6-#1.8	Homework	Printing, Variables, Plotting
#2.1-#2.5	Classwork	Iteration, Accumulation, Mapping
#2.6-#2.8	Homework	Iteration, Accumulation, Mapping
#3.1-#3.6	Classwork	Conditionals, Filtering Lists
#3.7-#3.8	Homework	Conditionals, Filtering Lists
#4.1-#4.6	Classwork	Textual Code, List Transformation
#4.7-#4.A	Homework	Textual Code, List Transformation

5 Evaluation of BlockPy

We now describe the results of a deployment of BlockPy. BlockPy has been used in an introductory Computational Thinking course for four semesters. This course is meant for non-Computer Science majors from the humanities, arts, and the sciences. They typically have no prior programming experience and have a limited understanding of the field. Therefore, they ideally model the anticipated BlockPy user.

In the Spring 2016 offering, 50 students were assigned 34 BlockPy problems over the course of 4 classes over 2 weeks (see Table 1). This focused use of block programming builds upon their notions of

algorithms, which they had previously seen during a 6-week introductory unit where students created algorithms using natural language and flowcharts. Most of the problems were assigned as classwork, with the expectation that any incomplete assignments were to be done as homework. Typically, classwork problems would give students starting code (usually in the form of a Parson' problem). Homework questions would have them complete similar problems from scratch. After the BlockPy unit, the curriculum continued in the Spyder IDE, as a way to transition students into a more authentic setting. To facilitate this shift, the last day of BlockPy material started in text mode, and encouraged students to become familiar with writing code in that form. BlockPy was not intended to be used for all programming in our course, and was faded in the transition to Python. In contrast to other curricula [38], for our college-level learners, the BlockPy scaffolding could be removed after 4 days. More information about the curriculum can be found in [31], and at the course's public site (http://think.cs.vt.edu/course_materials/).

BlockPy evaluation is based on two data sources. First, fine-grained logs were collected of the students' interactions with BlockPy, including any changes made to their code at the keystroke/block level and interface actions. Second, a survey was administered two weeks after the BlockPy component was completed. 41 out of 50 students gave consent for their answers to be released for research purposes, with 19 male students, and 22 female. 32% were freshmen, 39% were sophomores, 17% were juniors, and 12% were seniors.

The survey asked this multiple-choice question about where students felt that the BlockPy/Spyder transition should occur: "When do you think we should have STOPPED using BlockPy and started using Spyder?" In addition to an "Other" response, six alternatives were given: "Always", "Never", "The Same", and 3 points in the course, implying more or less use of BlockPy. The results of this question are discussed in Section 5.1.

This survey also had four free-response questions asking students about frustrating and helpful features in both BlockPy and Spyder. These free-response questions were qualitatively coded using a grounded-theory approach, resulting in generalized tags of student responses. Sections 5.1 and 5.4 describe the results of the analysis of this part of the survey.

5.1 The Environment's Effectiveness

In the free response section, students gave positive responses about BlockPy's block interface. 65% indicated the block interface as particularly helpful, and 34% indicated that the dual text/block interface helped. Consistent with the criticism of the automatic guidance, only 12% found that feature particularly helpful; our interpretation from this result is that students appreciated the guidance, but wanted more from it. In terms of other frustrations, 7 students (17%) suggested issues with using blocks (e.g., having to repeatedly drag blocks around). Other frustrations were with the problems assigned or the nature of coding in general. Comparatively, most criticisms of Spyder related to coding in general, rather than features of the environment (e.g., students described frustrations with Python syntax, trying to interpret errors).

Figure 5 shows the percentage of students who spent different proportions of time in block mode, over assignments. In other words, the red bars represent students who spent very little time in the Block mode (and were therefore predominately writing text), while the light-blue bars represent students who were predominately using the Block mode. For the first 3

TABLE 2
BlockPy Survey Qualitative Results

Environment	State	Tag	Percentage
BlockPy	Helpful	Block Interface	56.3%
		Dual Text/Block	29.2%
		Guidance	10.4%
BlockPy	Frustrating	Vague Guidance	31.2%
Spyder	Helpful	Better errors	31.2%
		Variable Explorer	31.2%
		Writing text code	8.3%

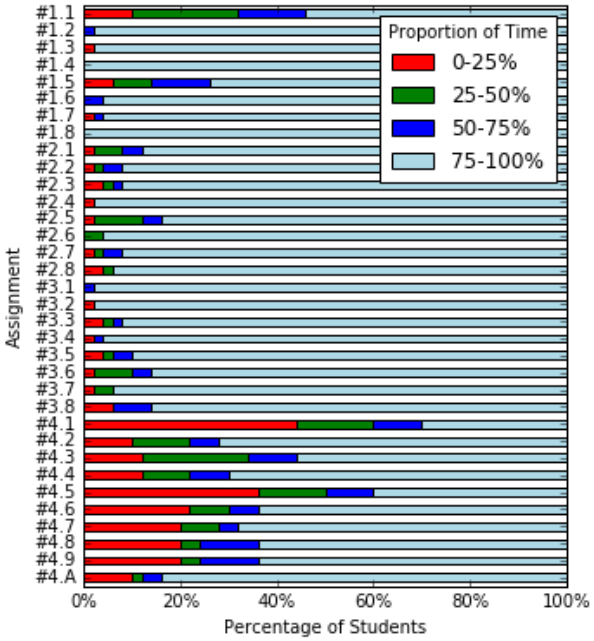


Fig. 5. Percentage of Students who Spent a Given Proportion of Time in Block Mode, by Assignment

days of the assignments, students mostly stayed in the block interface (with the first problem being a notable exception, since it was used to show students how the interface was dual-block/text). It is encouraging to note that some students did switch between the block and text editor in several early problems, if only to observe the resulting code. However, it is also clear that many students stayed almost entirely in the block mode, even during the final problems. This graph does suggest that more incentives and guidance should be given to direct students to pay attention or take advantage of the text interface, to build their competency with that form of their programs.

The last day of BlockPy began the transition to full textual Python programming. Students tended to spend more of the last day in the text interface, which was encouraged by the interface starting in text mode and the problems asking students to write their programs in text rather than blocks where possible. To prepare students for the transition, they are given a translation guide showing individual blocks and their equivalent textual form in Python. The day's lecture covered basic text syntax, and gave side-by-side examples of blocks versus Python text.

One effect observed in the transition to text was that students were confused what the keywords of Python were, compared to BlockPy. As previously described, the text on blocks is often more verbose than the actual Python syntax. This is intended as a feature to improve learners' understanding of the blocks. However, analysis of the logs suggest that this causes confusion for some students when they transition to writing text code. A crucial question is how wide-spread this problem is and how long it persists. We looked at three types of mistakes that students could make: writing `for each X in Y` instead of `for X in Y`, writing `set X = ...` instead of `X = ...`, and writing `if X then do ...` instead of `if X`. We found 20 students who exhibited this behavior in 29 different incidences across all the problems: 9 incorrect `for`, 17 incorrect `set`, and 1 incorrect `if`. Few students made the mistake on more than one problem. In over 60% of the cases, the student corrected their mistake within a minute, and in 23% the student corrected their mistake in 1-4 minutes. In the two worst cases, students persisted with the incorrect code for over 5 minutes and 7 minutes. It is worth pointing out that no student ended the assignment (successfully or not) with any use of the word `each`, `set`, or `do`. Nonetheless, it does seem prudent for the guidance to correct students who might be using such incorrect code forms.

The main toolbar in BlockPy gives students access to a number of features intended to help them complete problems. Some of these tools are standard editor features, such as undo and redo buttons. Some

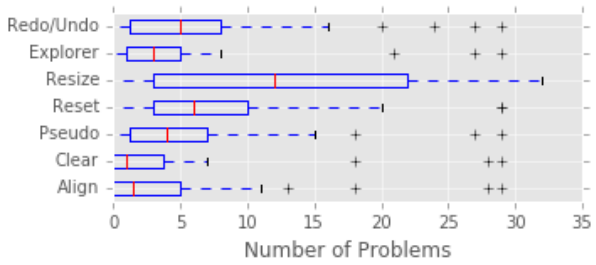


Fig. 6. Students' Use of Toolbar Features over Problems

of them, however, are more specific to the educational nature of the environment, such as the code explorer and natural language code generator (named `pseudo` in this version). Figure 6 reports on student use of these features across problems. Unfortunately, these data suggest that most students did not take advantage of these features. Deeper analysis found no significant correlations between student performance (as established by either time on task or number of successfully completed problems) and level of use of the toolbar features. The x-axis is the number of problems where a student used the particular feature at least once. In part, we attribute this underutilization to these features not being sufficiently emphasized in the instruction.

5.2 Managing the Data Science Context

Assignment completion rates and student survey responses indicate that the data science context that frames the curriculum was manageable by the students. Figure 7 describes student completion rates over the assignments. The bars are colored to indicate day (there were four days of BlockPy activities), and their brightness indicates homework vs. classwork. Figure 8 describes the distribution of time spent on each problem. 92% of the 50 students completed more than 60% of the 34 problems and 62% of the students completed more than 90% of the problems. The average student was able to complete most problems in 15 minutes, which was considered reasonable by the instructors.

While these aggregate results are positive, we found deficiencies with specific problems. Some seemed to take students much longer than anticipated, such as #3.7, which had students write code from scratch to identify the index of the minimum value in a list. As students progressed through the curriculum, there is a visible reduction in the percentage of completions. There is a similar reduction from classwork to homework. While the completion rate almost always remains above 70%, there was a noticeable drop-off on the last day. This is most likely caused by three things: fatigue on the part of the students (accumulated work load might have been overwhelming), the proximity

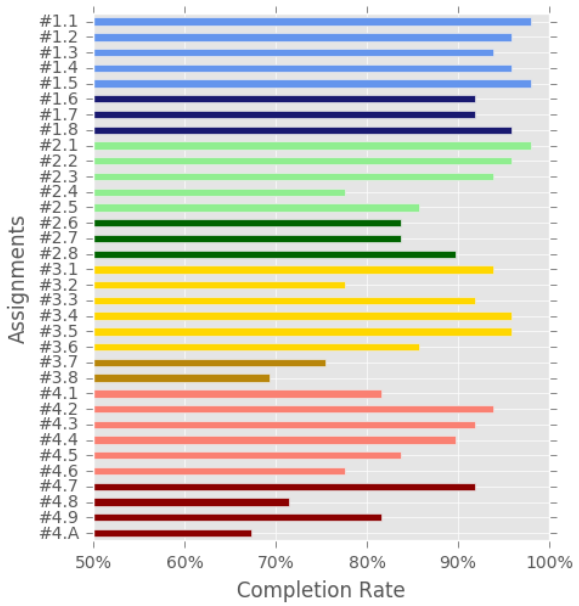


Fig. 7. Completion Rate by Problem (colors indicate distinct days, brightness indicates homework vs classwork)

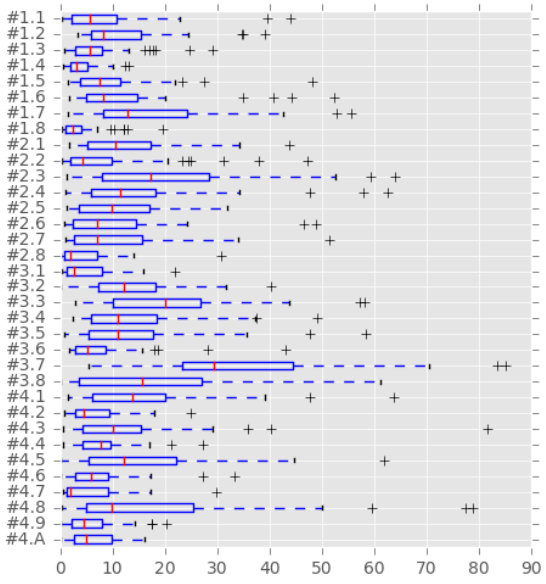


Fig. 8. Work Session Length (minutes) by Problem

to the end of the unit (which means that students had comparatively less time to work on these problems than earlier problems), and the fact that Day 4 is the transition to text mode and students struggle with the new syntax.

The survey asked students where they would prefer to make the transition from BlockPy to Spyder, and allowed to choose from a series of intervals in the course. The majority (28 students) indicated that the current location was appropriate, 6 students indicated that it should be later, 6 indicated that instruction should be kept in BlockPy, and 7 students indicated that it should be earlier. This provides justification for the relatively short duration of the BlockPy curriculum compared to subsequent sections of the course—the curriculum is intended to transition students into a more mature environment, and so is not meant to last for too much of the course.

5.3 Feedback Quality

In the free response section, there was little agreement about what was most frustrating about BlockPy, with one major exception: 34% of students agreed that BlockPy's automatic guidance could be frustratingly vague. This is partially biased by the timing of the survey. Earlier problems were (somewhat) intentionally equipped with more extensive suggestions and guidance than later problems, so students were most recently working with less helpful problems. Regardless, it is clear that students reacted negatively to the reduction in guidance. Giving less guidance in later problems was partially motivated by a desire to have students work more on their own, but was also motivated by the time-intensive nature of developing more sophisticated guidance.

Students suggested that error reporting in Spyder was more helpful than in BlockPy. In particular, they indicated that being able to identify the exact line that an error occurs in Spyder was tremendously helpful, and a major lack in BlockPy. Considering that the text mode of BlockPy does have this feature, we believe that students were only considering the block interface when making this assessment. However, it is an understandable concern. Errors in BlockPy refer to line numbers instead of individual blocks, a disconnect that was not considered enough by the designers.

Table 3 reveals a bigger concern than lack of guidance or inexact error reporting. The final submission from every student was analyzed using a flow-sensitive static-analysis algorithm that looked for code that, while valid and often matching the problem specifications, exhibited certain degenerative behavior. In the table, the first column is the type of semantic error, the second column is how many incidences were found in all student programs as a percentage of all programs submitted (50 students over 34 problems submitted 1587 programs), and the third column is how many incidences were found in programs marked correct as a percentage of all programs marked correct (1463 programs submitted that were correct). Figure 4 gives examples of some

TABLE 3
Incidences of Semantic Errors Detected by Static Analysis of 1587 Student Programs and 1463 Correct Student Programs

	All	Correct
Changed type of variable	60.8%	62.1%
Variable overwritten without read	50.9%	51.6%
Variable never read	16.8%	14.3%
Variable read without write	12.0%	9.10%
Iteration list used in iteration	7.48%	6.29%
Iteration variable unused in iteration	6.53%	5.13%
Used iteration list as iteration variable	6.02%	5.88%
Iteration over non-list	1.58%	.75%
Used unknown function	.63%	.63%
Iteration over empty list	.06%	.07%

of these types of errors: declaring a variable that is never read, reusing the iteration list as the iterator, and in one case even iterating over an empty list. Often, these errors are silently unreported because they are guarded against by unreachable code paths, or have no impact on the code.

6 Future Work

We now outline future work and directions for BlockPy. Some of this work is technical, some is design decisions that must be revisited in light of evidence collected in its evaluation.

6.1 Improved Evaluation

Further investigation of the efficacy of the BlockPy environment and our curriculum is a top concern. Beyond the evaluation described above, further experimental studies are planned. Currently, we have a major, ongoing experimental study to better understand the impact of more dynamic feedback. Baseline data has been collected, in the form of both specially created pre/post student assessments and fine-grained log data. This data will inform future iterations of the environment, the curriculum, and publications. Beyond this experiment, we hope to evaluate other components of BlockPy, including the dual block/text interface, and measure their impact on student learning and success.

6.2 Improved Guidance

A major place for improvement in BlockPy is the automatic guidance system. Currently, the system requires too much instructor effort, does not catch a number of problematic cases, and is not perceived to be as useful by its learners compared to other features. However, we believe that this feature has the most potential for helping students learn, based on the success of similar systems [39].

A hurdle for instructors is the cumbersome nature of authoring guidance. We are designing a new interface to streamline types of feedback that instructors most often give. Some of these features are related to ensuring that the students' output matches expectations. For example, symbolic program analysis can be used to ensure that students' output matches certain general formula instead of specific strings. Other features are designed to let instructors enforce restrictions about students' code: that they use certain language constructs, or that they have a declaration for a particular type of variable.

An addition to the environment now in progress is to integrate our static analyzer directly into the environment, to improve feedback. A major outcome of this integration will be static type-checking of the block system, preventing a number of common, systematic student mistakes (e.g,. attempting to connect a scalar variable to the list slot of an iteration block). Although Python is a dynamically typed language, we believe that beginners can benefit from stricter type requirements. Beyond type checking, we need to provide more support for students to understand syntax and run-time errors, particularly error messages reported by Python itself.

6.3 Tiered Block Interface

Transitioning students from the block interface to the text interface and eventually to a professional environment remains an unsolved problem. Although students seem to handle this fairly well, they did suggest some difficulties in the survey. We believe that establishing a more gentle gradient between blocks and text can assist in the transition. We propose using a tiered block interface to gradually shift from more verbose blocks into blocks that mimic literal Python syntax more closely (e.g., `for each ...` would change to `for`). At some point in the curriculum, the interface would change to the less verbose blocks in preparation for the eventual change in modes. This discrete change could also be supported graphically by the blocks moving closer and closer to regular text. For example, PencilCode uses faded transitions to suggest a continuous transition between blocks and text [19], and Greenfoot 3 uses a purposefully structured interface to make blocks seamlessly mimic text [20]

6.4 Missing Language and API Features

Although the underlying Skulpt execution environment is a full Python implementation, the entire library is not supported (including internal libraries such as SQL and popular third party libraries such as Pandas or SciPy). Additionally, the block interface

does not have bindings for every syntactical language element. Notable missing elements include try/except blocks, lambda expressions, and inline list comprehensions. Finally, the CORGIS library has a large number of other APIs that are not currently available through the interface. Development of the environment is driven by the needs of our curriculum. Although this is partially born of practicality, there is a tactical value to letting the interface emerge organically.

6.5 Missing Contexts

BlockPy was built around a data science context, with the hypothesis that this would be almost-universally appealing for students. However, some disciplines and age groups may find data science to be uninteresting. Other approaches to introductory computing have their own motivational and pedagogical benefits. For instance, animation and game design have both proven to be valuable contexts, albeit with a different design philosophy. Although results gathered in our research suggest the appeal of data science over other contexts [32], our results are not conclusive, and there is not a clear disadvantage to most other contexts.

6.6 The Data Science Process

BlockPy's take on data science could be seen as "data science on rails". That is, there are specific datasets exposed through a preconceived interface. Often, students become most motivated when they are able to explore their own datasets and their own problems. Although one solution is to broaden the number of datasets available, there is a long-term need for a general-purpose mechanism for users to access their own data sources through BlockPy. Previous work has been done to connect the Snap! programming environment with Google Sheets, so that students could access custom datasets [15]. Another major improvement to BlockPy would be to support the data science process at other phases, such as helping students to develop research questions or to interpret their visualizations.

7 Conclusion

We have described the design, development, and evaluation of a programming environment for beginners. It has a number of features including a dual text/block interface, a data science context, and immediate feedback. Results from an intervention with introductory students suggest ways to improve the environment. We happily make our tool freely available.

References

[1] J. Wing, "Computational thinking benefits society," *Social issues in computing*, 2014.

[2] M. R. Davis, "Computer coding lessons expanding for k-12 students," *Education Week*, 2013.

[3] K. Jordan, "Initial trends in enrolment and completion of massive open online courses," *The International Review of Research in Open and Distributed Learning*, vol. 15, no. 1, 2014.

[4] J. Wortham, "A surge in learning the language of the internet," *New York Times*, vol. 27, 2012.

[5] A. Forte and M. Guzdial, "Motivation and nonmajors in computer science: identifying discrete audiences for introductory courses," *Education, IEEE Transactions on*, vol. 48, no. 2, pp. 248–253, 2005.

[6] P. K. Chilana, C. Alcock, S. Dembla, A. Ho, A. Hurst, B. Armstrong, and P. J. Guo, "Perceptions of non-cs majors in intro programming: The rise of the conversational programmer," in *Visual Languages and Human-Centric Computing, 2015 IEEE Symposium*, 2015, pp. 251–259.

[7] M. Goldweber, J. Barr, T. Clear, R. Davoli, S. Mann, E. Patitsas, and S. Portnoff, "A framework for enhancing the social good in computing education: a values approach," *ACM Inroads*, vol. 4, no. 1, pp. 58–79, 2013.

[8] H. Bort, M. Czarnik, and D. Brylow, "Introducing computing concepts to non-majors: A case study in gothic novels," in *Proceedings of the 46th ACM Technical Symposium on Computer Science Education*, 2015, pp. 132–137.

[9] P. Guo, "Python is now the most popular introductory teaching language at top us universities," *BLOG@ CACM, July*, 2014.

[10] R. Schutt and C. O'Neil, *Doing data science: Straight talk from the frontline*. " O'Reilly Media, Inc.", 2013.

[11] T. W. Price and T. Barnes, "Comparing textual and block interfaces in a novice programming environment," in *Proceedings of the Eleventh Annual International Conference on International Computing Education Research*, ser. ICER '15, 2015, pp. 91–99.

[12] D. Weintrop and U. Wilensky, "Using commutative assessments to compare conceptual understanding in blocks-based and text-based programs," in *Proceedings of the Eleventh Annual International Conference on International Computing Education Research*, 2015, pp. 101–110.

[13] ——, "To block or not to block, that is the question: students' perceptions of blocks-based programming," in *Proceedings of the 14th International Conference on Interaction Design and Children*, 2015, pp. 199–208.

[14] M. Resnick, J. Maloney, A. Monroy-Hernández, N. Rusk, E. Eastmond, K. Brennan, A. Millner, E. Rosenbaum, J. Silver, B. Silverman *et al.*, "Scratch: programming for all," *Communications of the ACM*, vol. 52, no. 11, pp. 60–67, 2009.

[15] J. D. Hellmann, "Datasnap: Enabling domain experts and introductory programmers to process big data in a block-based programming language," Master's thesis, Virginia Tech, 2015.

[16] B. Broll, A. Lédeczi, P. Volgyesi, J. Sallai, M. Maroti, A. Carrillo, S. L. Weeden-Wright, C. Vanags, J. D. Swartz, and M. Lu, "A visual programming environment for learning distributed programming," in *Proceedings of the 2017 ACM SIGCSE Technical Symposium on Computer Science Education*.

[17] A. Feng, E. Tilevich, and W.-c. Feng, "Block-based programming abstractions for explicit parallel computing," in *Blocks and Beyond Workshop (Blocks and Beyond), 2015 IEEE*.

[18] Y. Ohshima, J. Mönig, and J. Maloney, "A module system for a general-purpose blocks language," in *Blocks and Beyond Workshop, 2015 IEEE*.

[19] D. Bau, M. Dawson, and A. Bau, "Using pencil code to bridge the gap between visual and text-based coding (abstract only)," in *Proceedings of the 46th ACM Technical Symposium on Computer Science Education*.

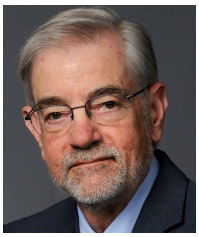
[20] A. Altadmri and N. C. Brown, "Building on blocks: Getting started with frames in greenfoot 3," in *Proceedings of the 47th ACM Technical Symposium on Computing Science Education*.

[21] S. H. Edwards, D. S. Tilden, and A. Allevato, "Pythy: Improving the introductory python programming experi-

ence," in *Proceedings of the 45th ACM Technical Symposium on Computer Science Education*, 2014, pp. 641–646.
[22] T. Tang, S. Rixner, and J. Warren, "An environment for learning interactive programming," in *Proceedings of the 45th ACM Technical Symposium on Computer Science Education*.
[23] P. J. Guo, "Online python tutor: Embeddable web-based program visualization for cs education," in *Proceeding of the 44th ACM Technical Symposium on Computer Science Education*.
[24] S. Graham, "Skulpt," 2010.
[25] B. D. Jones, "Motivating students to engage in learning: The MUSIC model of academic motivation," *International Journal of Teaching and Learning in Higher Education*, vol. 21, no. 2, pp. 272–285, 2009.
[26] J. Lave and E. Wenger, *Situated learning: Legitimate peripheral participation*. Cambridge university press, 1991.
[27] M. Guzdial, "Exploring hypotheses about media computation," in *Proceedings of the ninth annual international ACM conference on International computing education research*. ACM, 2013, pp. 19–26.
[28] M. Guzdial and A. E. Tew, "Imagineering inauthentic legitimate peripheral participation: an instructional design approach for motivating computing education," in *Proceedings of the second international workshop on Computing education research*, 2006.
[29] R. E. Anderson, M. D. Ernst, R. Ordóñez, P. Pham, and S. A. Wolfman, "Introductory programming meets the real world: Using real problems and data in cs1," in *Proceedings of the 45th ACM Technical Symposium on Computer Science Education*, 2014.
[30] K. Subramanian, J. Payton, D. Burlinson, and M. Mehedint, "Bringing real-world data and visualizations into data structures courses using bridges," in *Proceedings of the 47th ACM Technical Symposium on Computing Science Education*, 2016.
[31] D. Kafura, A. C. Bart, and B. Chowdhury, "Design and preliminary results from a computational thinking course," in *Proceedings of the 2015 ACM Conference on Innovation and Technology in Computer Science Education*, 2015.
[32] A. C. Bart, R. Whitcomb, D. Kafura, C. A. Shaffer, and E. Tilevich, "Computing with corgis: Diverse, real-world datasets for introductory computing," in *Proceedings of the 2017 ACM SIGCSE Technical Symposium on Computer Science Education*, 2017.
[33] N. Fraser *et al.*, "Blockly: A visual programming editor," *URL: https://code. google. com/p/blockly*, 2013.
[34] M. Haverbeke, "Codemirror," 2011.
[35] M. Ebert, "Skulpt matplotlib," https://github.com/waywaaard/skulpt_matplotlib, 2014.
[36] Y. Matsuzawa, T. Ohata, M. Sugiura, and S. Sakai, "Language migration in non-cs introductory programming through mutual language translation environment," in *Proceedings of the 46th ACM Technical Symposium on Computer Science Education*, 2015.
[37] K. Rivers and K. R. Koedinger, "Data-driven hint generation in vast solution spaces: a self-improving python programming tutor," *International Journal of Artificial Intelligence in Education*, pp. 1–28, 2015.
[38] W. Dann, D. Cosgrove, D. Slater, D. Culyba, and S. Cooper, "Mediated transfer: Alice 3 to java," in *Proceedings of the 43rd ACM Technical Symposium on Computer Science Education*, 2012.
[39] T. W. Price, Y. Dong, and D. Lipovac, "isnap: Towards intelligent tutoring in novice programming environments," in *Proceedings of the 2017 ACM SIGCSE Technical Symposium on Computer Science Education*.

Austin Cory Bart (Member, IEEE) received his PhD at Virginia Tech in Computer Science along with a certification in Learning Sciences. He received his undergraduate degree from the University of Delaware in Computer Science. His research interests are Computer Science Education, Software Engineering, and Program Analysis.

Javier Tibau (Member, IEEE) is a PhD candidate at Virginia Tech studying Computer Science. He is also an Assistant Professor at Escuela Superior Politecnica del Litoral (ESPOL). His research interests are in Human-Computer Interaction, and Computer Science Education.



Dennis Kafura (Member, IEEE) received his PhD from Purdue University. He is a Professor of Computer Science at Virginia Tech. He is the PI on two NSF IUSE awards both of which involved the development of a general education course in Computational Thinking at the university level using the BlockPy environment.

Clifford A. Shaffer (Senior Member, IEEE and Distinguished Member, ACM) received his PhD from the University of Maryland. He is Professor of Computer Science at Virginia Tech. His current research interests are in Computational Biology (specifically, user interfaces for specifying models and computations), Algorithm Visualization, and Computer Science Education.

Eli Tilevich (Senior Member, IEEE) received his PhD from Georgia Tech. He is an Associate Professor of Computer Science at Virginia Tech. His recent publications and current research focus on Software Engineering for Distributed and Mobile Computing and on Computer Science Education.