Institution: University of Kent

Unit of Assessment:

Title of case study: Greenfoot: Transforming the way programming is taught

1. Summary of the impact

Greenfoot is a software system to support the learning of programming at school level (age 13 upwards). During the REF period, over a million students worldwide have learned programming through Greenfoot: at school, in after school clubs and workshops, and privately at home. Greenfoot has helped to raise the profile of programming in schools and outside in a number of countries. The research described here has had impact on a variety of stakeholders, including pupils, teachers and those involved in national curriculum development. Greenfoot is currently downloaded more than 350,000 times/year and is in active use in thousands of schools. Greenfoot is one of very few systems, internationally, to have this level of impact on programming education.

2. Underpinning research

The research for this project has two strands: **pedagogical research** and **technical computer science research**. Our project group at the University of Kent carried out the research in both areas, including the development of new interaction techniques to support the learning of programming, designed and implemented the software, and conducted additional research on the usability and effectiveness of the resulting system. The overall Greenfoot project is reported in [2], [3] provides an introduction to parts of the ecosystem created as a result of the pedagogical research, and the Greenfoot textbook (see Section 4) embodies the pedagogical approach created as part of the Greenfoot project.

The project is led by Michael Kölling, Professor, University of Kent, (hereafter Kent), 2005-present, and the **initial pedagogical research and system design** was carried out jointly with Poul Henriksen, Research Associate, (hereafter RA) Kent, 2005-2009, in cooperation with John Rosenberg (Professor, La Trobe University) and Bruce Quig (RA, La Trobe). Later research work from 2007 to 2013 made **original contributions to HCI** in the context of novice programming systems, introducing interaction techniques that allow more experimentation and exploration, accelerate feedback, and – through this – **increase engagement and motivation**. This work allows new learning approaches that invert traditional curricula (allowing discussion of high level ("advanced") concepts before discussion of syntax; see [1], section 3). We contributed **novel interaction techniques** to programming environment technology that allow a more direct and experimental approach to interacting with a programming system. This work was carried out by Kölling, Ian Utting (Senior Lecturer, Kent), Neil Brown (RA, Kent) and Davin McCall (RA, Kent).

Pedagogically, we based the work on constructivist learning theories. We **specialised general constructivist theories** and applied them to the initial learning of programming, and specifically to the learning and teaching of concepts of object orientation ([1], sec. 3). This led us to formulate goals and targets for system characteristics, such as **interactivity**, **visualisation**, and support for **self-directed experimentation**, thus making original contributions to computing pedagogy.

The second strand of our research was concerned with developing computer system **abstractions** and **interaction techniques** to realise these goals in the context of a modern, statically typed, object-oriented language (Java, in our case). Some of the techniques are adapted from earlier highly interactive programming systems, such as Smalltalk and Self, and have been adapted to the statically typed nature of Java. Specifically, we developed a **new conceptual framework** of object-oriented programming concepts and concrete novel interaction techniques ([1, 2]).

Another important aspect of this project concerns **community** and **social support** for learners. Our research showed that the ecosystem (community, discussion, availability of material) has a major influence on learning success, and we developed a technology-supported online community around Greenfoot. This part of the project included the development of **novel social interaction**

models, combining aspects of **resource repositories** and **social networks**. These research contributions to computing education and HCI were reported in conference papers [4,5].

The research was supported by a series of industry grants over a period of several years. Each grant was for a one-year term, and each grant was awarded based on the outputs of the research previously completed. Grants received include $650,000 from SUN Microsystems (2005-2008), $450,000 SUN foundation (2009-2010), $1.1m from Oracle Corp (2011-2013) and $36,000 from Google (2011-2013), totalling more than US$2.2 million. These companies see the value of Greenfoot in "filling the pipeline" of software developers, thus sustaining the health of the industry.

3. References to the research [** - 1, 2,3 best indicate the quality of the underpinning research]

[1] ** *Game programming in introductory courses with direct state manipulation*. M Kölling and P Henriksen. In *ITiCSE 2005 Proceedings*, pp 59-63, Portugal, 2005. ACM.

[2] ** *The Greenfoot Programming Environment*. M Kölling. *ACM Transactions on Computing Education (TOCE)*, 10(4):21, 21 pages, 2010. [REF2 Kölling #1.]

[3] ** *Repositories of teaching material and communities of use: Nifty assignments and the Greenroom*. S Fincher, M Kölling, I Utting, N Brown, and P Stevens. In *SIGCSE Proceedings*, pp 107-114. ACM SIGCSE, 2010. [REF2 Utting #1.]

[4] *Motivating programmers via an online community*. Poul Henriksen, Michael Kölling, and Davin McCall. *Journal of Computing Sciences in Colleges*, 25(3):82-93, 2010.

[5] *A Tale of Three Sites: Resource and Knowledge Sharing Amongst Computer Science Educators*. N Brown and M Kölling. *Proceedings of the Ninth Annual International Computing Education Research Conference (ICER)*, pp 27-34, ACM, 2013. [REF2 Kölling #4]

4. Details of the impact

The Greenfoot system and research has a direct impact in several different ways:

- During the REF period, it has benefited more than a million school students in 49+ countries directly ([I1], [I2], all references to Section 5).
- It benefits thousands of teachers who use it to teach programming differently ([S2],[S3]).
- It has influenced national curriculum design in the UK ([S1]).

Impact for students. Students benefit by being able to achieve more tangible results more quickly, leading to increased **motivation and satisfaction**, as well as better **understanding of programming concepts**. Before using Greenfoot, many students were taught using text-based development environments designed mainly for professional programmers. These environments are difficult to use, force learners through large amounts of detail before achieving the first motivating impact, and possible outputs in reach of early learners are a long way off of meeting expectations of students who have grown up with interactive graphical software systems. Greenfoot removes all of these problems.

Many teachers have long been aware of this problem and have struggled to teach programming in a more engaging manner. This has been especially difficult if the goal was to teach modern concepts of software engineering, usually with an object oriented language. **Greenfoot helps teachers** by giving them a tool to meet their goals – teaching software development principles and object orientation in a modern, graphical context. The impact is aided by the availability of a Greenfoot-based textbook: *Introduction to Programming with Greenfoot – Object-Oriented Programming in Java with Games and Simulations.* Michael Kölling. Pearson Education, 2009. ISBN-13: 978-0-13-603753-8. More than 16,000 copies of the book have been sold, providing further evidence of the popularity of this approach.

User engagement. User engagement in the research results and the resulting software has been achieved via a number of different channels. These include keynote talks at **educational conferences** in several different countries, research talks and invited talks at conferences, and a **large number of teacher and student workshops**. Publishing the software itself is not sufficient

to create lasting impact; it was highly effective to go out to conferences where we could interact with stakeholders and present the system to them directly. Over the last three years, we have reached more than 300 teachers directly in face-to-face workshops. A **Greenfoot channel on YouTube** (http://www.youtube.com/user/18km) with instructional videos has received more than 290,000 views over two years.

Computing at School (CAS). Our research group works with the Computing At School (CAS) group (www.computingatschool.org.uk), which aims to improve the provision of computer science in schools in the UK. Greenfoot has become one of the frequently used tools in the group's activities, including teacher training workshops. In a letter [S1] supporting this case study, Simon Humphreys, BCS and coordinator of CAS, wrote: *"The pedagogy that underpins Greenfoot is exemplary. It has an active, supportive, worldwide community, tutorials and teaching plans. It has a special place with pupils at KS4 and A Level and CAS are privileged to be able to work with the Greenfoot team in supporting classroom practitioners."*

Feedback. The impact for students and the effectiveness of the dissemination is evidenced by frequent unsolicited feedback from teachers. Following are two typical quotes from instructors:

"By the way, I gave my Year 12/13s a choice of what to do their projects in, and 16 out of 18 chose Greenfoot. The progress they've made so far compared to this time last year on VB or php/Javascript is amazing. I see a whole pile of A's appearing in due course!"
– Andrew Tringham, Teacher, Archbishop Tenison's School, Croydon, (see statement [S2])

"On Monday they could stay at home for me to see and exercise your 'Joy of Code' movies. With the notion that they would receive an assignment on Tuesday. I'm always very suspicious, and I didn't thought that they would go seriously through the material. Monday at midnight, I gave the assignment free. Normally in the morning when I enter a classroom, IT-students are still half sleeping or reading the online journal, or checking their Facebook,… Yesterday, it was amazing. The room was fully occupied before 9 o'clock with 80 students! There was an enormous rumor. I saw drawings, heard discussions, saw already things pass on a colored screens. So, they needed no introduction, yet there were already fully occupied with their scenario. The whole day long they were working in pairs on their scenario and asked many questions. Some students went on Monday through all your 33 movies of the Joy of Code. Incredible! For me, one of the big advantages of Greenfoot is, that the students 'see' immediately result. And therefore they are urged to get further on."
– Chantal Teerlinck HUB-Hogeschool Universiteit Brussel (see statement [S3])

James Gosling, the creator of Java, also commented on Greenfoot after seeing his daughter use it: *"Greenfoot makes it fun to learn programming. It starts out with very logo-ish exercises (moving a wombat around via method calls to find food), then automating the characters so that they can find their own food, and progressing to a variety of video games. The scenarios really absorb kids." (Full statement available.) (see statement [S4])*

The direct feedback from teachers shows that the goal of increasing motivation and engagement in learners is being reached, and that the Greenfoot system has indeed made a significant contribution in causing change in students' attitudes. The value as seen by the wider community is also evidenced by a significant number of **volunteer contributions to the project**, often in the form of translations. The Greenfoot user interface has been translated into 12 languages (including Chinese, Portuguese, German and Spanish), and the Greenfoot tutorials have been translated into seven languages. These translations were produced by volunteers who invested significant amounts of time to make these contributions.

Scaling up. For international support and distribution and the scaling up of face-to-face support, we have established **8 *Greenfoot Hubs*** in different parts of the world (concentrating mainly on the US, following our user distribution, see http://www.greenfoot.org/hubs/). These Hubs are run by volunteer academics from other institutions in close coordination with us, and they provide local Greenfoot training and support, using resources developed and shared by all hubs. In 2012, the hubs have delivered 12 teacher training workshops.

To establish a self-sustaining community we developed two supporting websites – one for end users (students) and one for teachers. The user site provides direct help and discussion about Greenfoot programming and the teacher site provides teaching material and advice on educational topics. The **Greenfoot user site** currently has **approximately 4500 users** subscribed and receives more than 47,000 site visits (210,000 page views) per month. It contains more than 2,500 programmed Greenfoot examples, uploaded by approximately 1,900 distinct users, and an active discussion section. The **Greenfoot teacher site**, the Greenroom, currently has more than **2,400 teachers** signed up, who uploaded more than 120 resources and are engaged in discussion. We estimate that through these teachers alone we reach more than 30,000 students.

Downloads. The impact is plainly evidenced by download numbers. The Greenfoot software is currently **downloaded more than 350,000 times per year**, with annual downloads increasing.

National and international reach. Most of the impact is international, with adoption spread through more than 49 countries (see section 5, reference 2). Adoption is strongest in North America and western Europe. Nationally, Greenfoot is now also highly recommended by **Computing At Schools**, who are involved with the development of UK curricula (see reference 9, below) and Greenfoot is referenced in **national curriculum documents** as one of the useful tools to enable the teaching of programming for that age group. Through this, the research has an impact in changing the way computing is presented in UK schools.

In conclusion, we note that Alison J. Derbenwick Miller, Vice President of Oracle Academy confirms the impact and reach of Greenfoot in a statement [S5]: "*Our continued philanthropic investment in the project reflect our recognition of the impact and importance of Greenfoot to support the learning of computer science and programming using [Java]. Greenfoot makes initial programming more easily accessible and has helped millions of beginning programmers to become engaged with software development. … Oracle Academy has chosen to include Greenfoot in its Java Fundamentals course curriculum used by K-12 teachers globally. … During the 2013 academic year Oracle Academy delivered introduction to Computer Science training to approx. 6,000 teachers worldwide. The Greenfoot environment is an important part of our Java curriculum, and we are proud to continue to support its development at the University of Kent.*"

5. Sources to corroborate the impact

Corroborating statements have been received from

[S1] http://www.cs.kent.ac.uk/research/REF2014/Humphreys.pdf [Computing at School, BCS]
[S2] http://www.cs.kent.ac.uk/research/REF2014/Teerlinck.pdf [Schoolteacher, Belgium]
[S3] http://www.cs.kent.ac.uk/research/REF2014/Tringham.pdf [Schoolteacher, UK]
[S4] http://www.cs.kent.ac.uk/research/REF2014/Gosling.png [Inventor of the Java language]
[S5] http://www.cs.kent.ac.uk/research/REF2014/Oracle.pdf [Industrial sponsors and users]

Other information

[I1] Greenfoot user statistics: total annual number of users > 350,000 in 2012, *stats.greenfoot.org*

[I2] Greenroom: number of subscribers (who are instructors) > 2400 *greenroom.greenfoot.org*. To see map of subscribers in 50+ countries, log in with guest@example.com / guestpassword

[I3] The impact on CS education is evidenced by the ACM SIGCSE "Outstanding Contribution to Computer Science Education" award to Michael Kölling in 2013 (*http://www.sigcse.org/programs/awards/outstanding*) and the "Premier Award for Excellence in Engineering Education Courseware" awarded to Greenfoot in 2010 (*http://www.k-grayengineeringeducation.com/blog/index.php/ 2010/10/29/2010-premier-courseware-award-winners/)*

[I4] The value ascribed to the system by industry is shown by an industry award, the "Duke's Choice Award", awarded to Greenfoot in 2007, *http://www.cs.kent.ac.uk/news/2007/GreenfootPrize*

[i5] The impact of the online videos on the general population is evidenced by view numbers on the Greenfoot Youtube channel (>290,000 views; see *http://www.youtube.com/user/18km*).