Educational robots for teaching programming to youths

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Date

# Abstract

 **What you set out to do and why**

 **How you did it**

 **What you found**

Do this last

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# Introduction

Robots have been used to further education and to increase engagement in a range of topics. For example, in secondary school mathematics robots have been used to demonstrate geometric transformations. Programming is a skill with which many have encountered difficulties understanding and persisting with, one cause is a lack of motivation and enthusiasm towards the topic. Another cause is that the interaction with the computer is limited to the computers screen preventing any physical or real world feedback. In this research an interface to allow the use of Scratch, a user friendly programming language to control a Thymio-II robot was created to allow users to have their programs affect the real world.

* The first objective of this project is to understand the Scratch and Thymio II software in such a way that an interface can be built from that knowledge. By understanding how to communicate between the software components fully before planning the interface the design process can be optimised.
* Another objective is to create an interface between the programming language Scratch and the Thymio-II robot. This would be the main artefact from this project and would allow users to program in Scratch to control the Thymio-II robot.
* For this project the Scratch 1.4 would be adapted to conform to the interface to improve the ease of use. This would make use of Scratch 1.4 code to manage communication with the interface as well as to store and update variables from sensors.
* Another objective is to run a focus group session. Materials and tutorials appropriate for the attendants of the session will need to be created and the event will need to be organised and advertised.
* Finally the results of the focus group will need to be evaluated by compiling questionnaire results and analysing the answers to see if the Scratch and Thymio interface is usable.

# Literature Review

Programming and computer skills are becoming increasingly important as the influence of the internet and the power of computers grows, programming has even been called the 'second literacy'. Despite this there are still significant barriers to education in this field and few attempts to integrate it in to other computer related topics. This project will use the language Scratch and the Thymio II as they have both been shown to be good at introducing people to the topic of programming and robots as well as maintaining interest and creating enthusiasm.

Scratch is a language developed at MIT which has been used in education with broad success. Scratch allows for the use of most programming concept without requiring the user to be aware of syntax through the use of blocks. As well as being easy to use it is also free to use and has a large community with a wide range of users from 4 to 60 year olds meaning support can be found relating to the most basic of tasks to complex ones. One study found that during a Harvard Summer School for Computer Science course that 76% of students felt that using Scratch as an introduction help them when they later moved on to java, students also found it was more rewarding to have visual feedback on what they had programmed than just having a text window (Malan and Leitner, 2007).

Amongst the reasons why teachers don't accept technology in to the class as readily as they do other tool are stress and fear of failure. When a teacher tries to teach using methods in which they have little experience they often find that it can be daunting and cause stress. Introducing people to Scratch has both caused people to be more likely to include programming in lessons and to worry about failing less when they consider programming courses or sessions. A study of students learning to become preschool teachers were given an introductory lesson in computer programming and found that interest in using technology in the classroom increased from 80% to 92%. As well as this they found that 65% found Scratch easy to use and 85% found it simple and understandable (Fesakis and Kiriaki, 2009).

One challenge facing robotics in education is the price of the platforms and how easy they are to use. The Thymio II can be bought for around £100 which is cheaper than alternatives such as the LEGO Mindstorm while still having most of the feature. Besides the LEGO robot there are few available robotics platforms that are simple enough that they can be used for an introduction to the topic while also being capable enough that they can perform complex programs. The Thymio II is a powerful system and with Scratch it would mean that it can be easily picked up by beginners while still being able to perform some complicated programs. Scratch include features such as the ability to create object orientate programs as well as use multithreading, and is seen to have one major limitation which is recursion which has been purposely left out so that beginners would not feel threatened by the complexity (Harvey, B. 2010).

Robots have been used before with other aspects of programming to create courses that have proven to create very enthusiastic students. For example, at the University of Lincoln robotics was taught alongside computer vision, this lead to positive results in practical sessions including some students ended up going far beyond the brief of their assignments with some advanced feature that they researched and implemented under their own direction. (Cielniak, G. et al, 2013), this suggests that enthusiasm can be created with practical assignments using robots.

The Thymio II is a programmable robot with a wide variety of sensors and methods for feedback. It has 2 wheels for movement, a speaker for audio output and several lights, some of which are programmable and others which indicate the feedback from the distance sensors. There are 9 distance sensors to prevent it from falling off objects and to detect thing in front or behind it. It also has a 3 axis accelerometer, a microphone and an infrared sensor for remote input. With these features the Thymio II is well suited to education as it can be applied to a lot of situations. The Thymio II is the result of testing amongst children with the Thymio II. After running courses with the Thymio 89.2% of parents thought the session was educational and 78.5% thought that it had increased their child's interest in robotics (Riedo, F. et al 2012)

### Conclusion

Several conclusions can be drawn from this research. Firstly, that robots used in education can lead to increased practical achievement and can motivate students to go beyond the constraints of an assignment. Secondly, that Scratch is a very powerful but simple language with a majority of standard features while still remaining user friendly and accessible to beginner programmers. As a result of this it can be used to introduce a variety of people to programming and to reduce their anxiety and discomfort with programming. Thirdly, that the Thymio II is the second iteration of a robot produced through extensive user feedback and as a result is very capable and adaptable platform.

# Methodology

## Project management

Agile/learn/extreme

## Software Development

**Needs references? - yes**

In order to carry out this project an interface needed to be developed. The interface needed to work with Scratch 1.4 and the Thymio-II robot. This piece of software is largely unique in its purpose and so it needed to be developed with a method which could accommodate the flexibility that would be necessary to complete it. A variation on the waterfall method was chosen called incremental. Incremental is a method which employs small waterfall stages allowing for reflection and adjustment after each (Cms, 2005).

Developing the interface required overcoming unique challenges which were specific to this type of software, as a result some segments of the code needed to be rewritten or upgraded as new knowledge was gained. Incremental development allows for the software to be reviewed after each task is completed so that improvements to the code can added as tasks at suitable points in the development. Consistently improved code was important for this project as this meant the scope of the interface could expand without causing conflicts with obsolete code. Scratch 1.4 and the Thymio-II robot both needed to communicate with the interface and as neither components were built with compatibilities for the other the development process had to account for impassable obstacles which could result in fundamental aspects of the interface needing to be changed such as the programming language or the methods of communication. Incremental development suited this as its review process gives an opportunity to evaluate the current state of the program in addition allowing newly acquired knowledge to be applied to the situation.

The result of using this method meant that during initial development when experimentation took place there was little commitment to carrying on with a particular plan. Following this unsuccessful ideas could be discarded quickly and so that the core functionality of the interface was more robust. The incremental aspect of the development meant that the software was completed in discrete and complete chunks such that each iteration resulted in a working prototype with individually changing features. This discrete improvement meant that progress could be monitored easily by reviewing which features had been added or changed. In addition to this the scope of the interface was expand where appropriate during the brief review periods to include feature which previously could not be planned for as the relevant knowledge about the system was not known.

One issue with the method was that features were often completed on their own without consideration for future iterations. This caused large amounts of the interface to need to be rewritten, although this had the advantage of ensuring the program was built with recently acquired knowledge it also caused the progress of the project to slow down. With a more rigid method features could be anticipated and prepared for better. Another issue with the development method was that while it was useful for increasing the scope of the software and monitoring progress it wasn’t very useful for estimating the tasks remaining and the time they would take. As the software needed to be functional before any testing or studies could take place

Cms, (2005) *Selecting Developing Approach*. [Online] Available from: www.cms.gov/Research-Statistics-Data-and-Systems/CMS-Information-Technology/XLC/Downloads/SelectingDevelopmentApproach.pdf [Accessed 18 October 2014].

## Toolsets

Several tools were required to complete this project. In this section they shall be listed and their inclusion will be explained with comparisons to alternate software. The tools used in this project were as follows:

* Thymio-II robot
* Aseba
* Scratch 1.4
* Python 2.7.9
* Gedit
* GitHub
* Microsoft office suite

### Thymio-II

As the aim of this project is to create the tools to enable education using robots, a suitable robot was needed to work with. When deciding which to use several available options were considered and evaluated before the Thymio-II was chosen. The Lego Mindstorm NXT, the WowWee Rovio and the Aseba Thymio-II were compared and the results are shown in the table below. As the robots were going to be used in an interface some normally prevalent aspects such as ease of use were not important as they would be hidden by the interface.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Robot | Cost | Connectivity | Sensors | Actuators | Battery life |
| Thymio-II | £84 (€115) | USB | Proximity – 7  Ground sensors - 2  Rotation – 3 axis  Sound sensor - 1 | Wheels - 2 | 3.7 Volts  1500 mAh |
| Mindstorm NXT | £440 | USB  Bluetooth | Touch sensor – 1  Light sensor – 1  Sound sensor – 1  Ultrasonic - 1 | Motors – 3 | 7.4 Volts  2100 mAh |
| Rovio | £500 | USB  Wi-Fi | Camera – 1  Proximity – 1  Microphone – 1  Speaker - 1 | Wheels – 3  Camera mount | 6 Volts  3000 mAh |

Out of all of the robots the Thymio-II was the cheapest at 19% of the NXT, the next cheapest robot. As the aim of the project is to encourage people to learn with robots it is important that the equipment is accessible, the other robots are less accessible due to their prices. The camera and the microphone on the Rovio cannot easily be integrated in to Scratch 1.4 and so would have little functionality remaining. The NXT has a variety of sensors that can be used in Scratch 1.4 as they can be simplified in to raw numbers. The Thymio-II sensors are also varied, on top of this there are lots of them for users to make use of. The camera mount on the Rovio is largely useless without using the camera. However the wheels on the Rovio allow for omni-directional travel due to rollers on the wheels making the Rovio quite mobile. The three motors on the NXT can have wheels attached or they can be used in other configurations such as the power tracks or simple legs. The Thymio-II has two wheels and a small plastic nub that slides over surfaces. The wheels on the Thymio-II have generic construction points that are compatible with Lego, but unlike the NXT the Thymio-IIs wheels are in fixed positions. The length of time a battery charge will last in one of the robots is dependent on the actions the robot is taking. Although the NXT and the Rovio have larger capacity batteries they also use the power faster due to their features such as cameras and ultrasonic sensors. The biggest flaw with the Thymio-II is the connectivity. While the other robots have wireless connection options the Thymio-II does not, this could be augmented with a small ARM computer added to the Thymio-II using the building block mounting points on its top. As well as this there has been research in to integrating a wireless interface without a significant impact on battery life (Retornaz, P. et al, 2013). After considering these three robots the Thymio-II stood out as the most suitable mostly due to its price and quantity of sensors.

### Aseba

The Aseba software package gives the user access to the Thymio-II programming environment. The programming environment was used to quickly test concepts without having to fully implement them. Programs can also be loaded on to the Thymio-II which can be executed remotely. The Aseba software also includes Asebamedulla which is required to communicate to the Thymio-II from external software using D-Bus.

### Scratch 1.4

A programming environment is required so that the user has a means of interacting with the interface. This artefact of this project is aimed at young people and people new to programming. As such the environment user’s use will need to be easy to use and intuitive. As well as this the environment will also need to allow for remote input.

Scratch makes use of blocks rather than text for coding. This prevents users from encountering syntax errors and means that they are not required to memorise key words or commands. All of the blocks that a user can use are available in a window to the left. The blocks are also sorted by type with categories such as operators, control and variables so they can be easily found. All of the blocks in Scratch can be execute by themselves allowing programmers to test and explore code easily (Maloney, J. et al, 2010).

There are currently two versions of Scratch available, version 1.4 and 2.0. Scratch 2.0 is an update to Scratch 1.4 and has been ported in to Adobe Flash to allow it to run in a web browser. The update includes customizable blocks, a sound editor, time blocks and image editing. Scratch 2.0 can be used offline but it requires Adobe Air to run which means installing Scratch 2.0 on Linux operating systems is difficult requiring use of the command line. Scratch 2.0 has also had its remote connections server removed as it now runs in a web browser. Scratch 1.4 however has a remote connections server as well as being easy to install on all operating systems.

Due to the remote connections as well as a standalone Linux version Scratch 1.4 was be used for this project. Another significant advantage of using Scratch 1.4 is that it can be run on a Raspberry Pi, a cheap and accessible arm computer, making the interface more accessible.

### Python 2.7.9

While the user facing side of the interface needs to be easy to use the actual interface itself needs to have the complexity to manage commands between a robot and a programming environment. With this in mind the language used to program the interface needs to be the most suitable to the two chosen components, in this instance Scratch 1.4 and the Thymio-II.

During research it was discovered that the Thymio-II allows for control over D-Bus. This was built primarily for debugging and allows access to all variables and functions and gives full control over Thymio-II. Scratch is a popular programming environment and already has modules to allow scratch to communicate with some programming languages.

Python is one of the languages with both a D-Bus module. The D-Bus module allows for connections to the Thymio-II such that it can be controlled. There is also a Scratch 1.4 connection module called scratchpy (available at: <https://github.com/pilliq/scratchpy>). Scratchpy manages all communication between Scratch 1.4 and Python allowing messages and variables to be sent and received.

Although the interface is not required to be accessible to users it is a desirable feature as users may want to advance from Scratch 1.4 at some point while still using the interface. Python is popular language with lots of support and documentation available online. As well as this it also has a garbage collector meaning the user doesn’t need to manage the programs memory. Another attractive feature is the way that variables in python don’t need to be declared explicitly but instead are inferred by the interpreter.

Due to the ability for Python to communicate with both the Thymio-II and Scratch 1.4 as well as its support and user friendly features it is the most suitable for this project.

### Gedit and Idle

As the interface will need to be programmed in a Linux operating system a suitable editor is also required. Python is an interpreted language and so does not need a compiler and is instead read and executed at runtime by a Python interpreter. As a result creating the interface does not significantly benefit from an integrated development environment (IDE) like C based languages or Java. Instead Python can be programmed using a text editor.

For this project two editor were used. Gedit is the default text editor for GNOME based desktop environments. It supports line counting and simple syntax highlighting for recognised key words. Gedit is Light and quick to use allowing for a program to be amended quickly and then saved and run in the terminal. One advantage of this is that the finished interface was executed from the terminal so while programming the output from the interface was the same as what a user would be expected to encounter.

The other editor was Idle. Idle is in actuality an IDE that has a built in interpreter allowing code to be tested quickly. Idle also has syntax highlighting like Gedit but Idle also has auto completion for object members. Idle is useful for writing large segments of code as it can check for errors and help with auto completion. Python uses indents to define scope and Idle manages scope automatically again making development easier.

As Gedit is quick and easy to use but lacks some features and Idle is fully featured but not so quick to start and runs code in an environment different to the one the users will use both editors have been used.

### Microsoft Office

As part of a study a questionnaire and a consent form will be required. The Microsoft Office suite includes a fully featured word processor with a range of formatting options allowing it to be used for creating a simple consent form and a questionnaire.

The Office suite also include Microsoft Excel which is a spreadsheet program. This program can be used for contacting and presenting data via its ability to tabulate and graph raw data. As it is part of the same suite as Word graphs and tables can be copied directly from one program to the other with no issues with formatting. On top of this changes to a table, a graph or the data in Excel are transferred directly in to word ensuring that word always has up to date data.

An alternative to word would be Libre Office, a free office suite similar to Microsoft Office. Libre Office contains both a spreadsheet program and a word processor but lack the formatting options of Word and the interconnectivity that Word and Excel share.

### GitHub

In order to effectively manage work as well as maintain backups and manage changes GitHub was used. Git is a version tracking software which allows a user to build a repository for a project and enter messages that are associated with changes they make, these changes are stored on a database allowing mistakes or errors to be reverted such that the repository returns to a functioning state.

GitHub extends this versioning software so that repositories can be stored online. This means that a project is backed up on all computers it is stored on as well as on the GitHub servers. Being online the code is also public access allowing people to create forks in the project so that they can develop it themselves and download the project for use. This gives users an easy way to download the project as well as a safe way to back up and store the project.

## Research methods

To determine the success of the project the usability and the user friendliness of the interface produced needs to be evaluated. To do this, qualitative research needs to take place in an environment where the users can have access to the hardware and software and their experiences can be recorded. To achieve this, a focus group will be used. A focus group is when multiple individuals gather to perform 'focused' task and influence each other with their ideas. This will be used as it is easy to implement as compared to other methods, has a low cost to create and run and also because it allows for a large sample size (Freitas, H. et al, 1998).

The focus will use the software to complete a series of tutorials and task, they will then be handed a standardised questionnaire in which they will be asked about their experience with the interface. The results will then be compiled and analysed.

# Design

## Introduction

In this section the components of the interface will be broken down and the external communication options will be analysed. After this the design of the Interface will be presented.

For this project an interface between Scratch 1.4 and the Thymio-II robot was developed. In order to build this the architecture and functionality of each component had to be evaluated and designed for. The Scratch 1.4 programming language contains trigger blocks which react to events allowing for event based programs to be developed. On top of this Scratch 1.4 supports concurrent processes and thread based programming (Maloney, J. et al, 2010). In relation to building an interface this flexibility allows for a range of approaches to be made. The Thymio-II makes use of its own programming language where code is executed when events are triggered. These events include timers, sensor updates and user created functions (Shin, J., and Magnenat, S. 2014). This event based programming caused conflicts with thread based programs in Scratch 1.4. The interface was decided to be built using python which supports multithreading as well as event based programming.

## Scratch 1.4 communication

Internally Scratch 1.4 uses broadcasts which sends a message to all objects in the project, if an object contains a trigger for that specific message then it will be executed. As well as broadcast the variables in Scratch 1.4 are global allowing objects to communicate values directly.

Scratch 1.4 already has support for external sensors in the form of remote sensor connections (RSC). Enabling the RSC causes scratch to run a server which will transmit all variable changes, variable creation and broadcast to all connected devices. Broadcast are sent as a string containing the value of the message being broadcast. Variable changes and creation are sent with the variable name and the new value. Unlike standard variables in Scratch 1.4 variable sent over the RSC will be received as sensor values which cannot be edited. Broadcasts can also be received by the RSC server which will broadcast the message to all objects in the Scratch project. Variables can set and created by send the RSC server the variable name and its value.

The ability for variables to be created through the RSC server allows for the interface to send any value without Scratch or the interface encountering a fatal error. Sensor values is the main way for data to be communicated in to Scratch 1.4 through the RSC server, as the value can’t be edited it also won’t be transmitted back to the interface. Due to the inability to easily edit standard variables in Scratch 1.4 from the interface feedback to the user about parameters entered cannot be easily given.

## Thymio-II communication

Besides the custom built software the Thymio-II supports communication over D-Bus, a proprietary Linux protocol for communication. Using D-Bus variables can be requested. Requesting variables requires a handler to manager the different variable type that can be received. Variables on the Thymio-II can also be adjusted. The Thymio-II changes its state based of its local variable such that a variable corresponding to a LED can be altered to change the brightness of that LED.

Receiving messages from the Thymio-II requires a command to be sent first and then a response containing data to be sent back. Requesting large amounts of data often can cause network latency to increase and prevent other messages from being received. Sending commands to the Thymio-II requires variables to be changed, after this the Thymio-II will then have to recognise these changes and then relay the changes to the actuators. This method of sending commands is simple and handles timing and optimisation automatically, however as the Thymio-II might not react instantly some commands might be delayed.

## Interface

[Diagram]

# Development

## Introduction

This section will explain the development process of the project and will go over the steps taken to create and use the interface. In addition any issues encountered will be described along with their solutions. The interface will be explained first followed by the theory behind connecting the interface to the robot.

## Interface implementation

The first task that had to be undertaken was enabling Python to communicate to the Thymio. After some research it was clear that Asebamedulla could be used to allow a D-Bus connection to communicate with the Thymio-II. Using Pythons D-Bus module the code could connect with the Thymio-II via Asebamedulla using a D-Bus Interface and the Asebamedulla D-Bus name (figure [X]).

Figure 1: The D-Bus network being created to Asebamedulla

Now there was a connection to Asebamedulla which would then send data through to the Thymio-II robot which would apply them as appropriate. The Python code now needs to retrieve and store the current values from the Thymio. To do this a loop was created that would send a command every 100 milliseconds telling the Thymio to send the current values from its proximity sensors. The sensor data could be accessed using the previously declared network variable along with the GetVariable command. The GetVariable command required several parameters to function. Firstly it needs the device to be specified which in this case is the Thymio-II. Next the variable that is meant to be returned is set, for the proximity sensor the string “prox.horizontal” is sent. The next parameter is a function to handle the data and finally there needs to be a function to handle any errors. The variable handling functions make use of variables declared with appropriate types meaning that for each sensor type the data can be stored directly in to a variable. The error handling receives an error message in the form of a string and cause the current code to quit (figure [X]).

Figure 2: The variable handling for receiving a variable

Due to the nature of Python variables can be declared with a type and then referred to outside of their initial scope by using the key word “global”. The proxSensorVal holds an array of 7 floating point variables where each is the current distance the corresponding proximity sensor. The groundDeltaVal stores 2 values for the downward facing proximity sensors which are used to tell if there is a surface below the front of the robot. The accVal stores 3 floating point variables, each of which representing an axis from the Thymio-II’s accelerometer.

Before the interface and send commands the code first needs a way of dealing with user input. An array of strings is used where each string is the text for a command (e.g. “forward”). This array is used to set a single string to a variable called command which stores the current command. As the loop progresses a series of if statements check for the different commands and runs the appropriate command.

The Thymio-II deals with movement by setting a target speed for each wheel and then automatically tries to achieve this. The interface can take advantage of this by sending a command to set the target speed variables to the required speed instead of trying to access functions on the Thymio-II. The command to set the variables makes use of the network object and is called SetVariable. This function is similar to the GetVariable function in that it requires the device and the variable name but then you send the value you want to set the motor to (figure [X]).

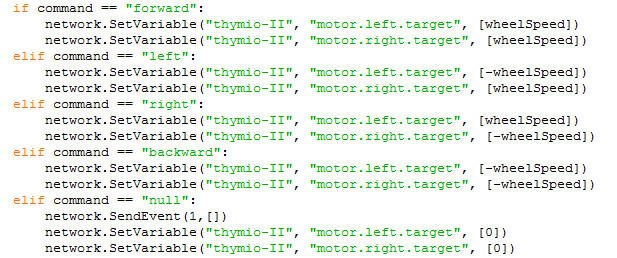


Figure 3: Setting wheel target speed depending on command

Now that data has been received and commands can be sent the interface now needs to communicate with Scratch 1.4. Scratch 1.4 has a built in server for robot communication which allows values to be read in. On top of this, with the server enabled Scratch 1.4 will send all broadcasts and variable changes over the network. To connect to this the Python code will make use of a python module called scratch. This module connects to Scratch 1.4 and handles all data traveling between the interface and Scratch 1.4. To initialise the connection to Scratch 1.4 a Scratch object is made, during this the host IP address is given (the address to the machine running scratch) and the module establishes the link. At this point any broadcast made in Scratch 1.4 will be sent and added to the back of the received commands queue.

As the main loop needs to keep running to update sensor data

1 connect to Thymio -  
2 receive data -  
3 send commands -  
4 connect to scratch -  
5 Receive commands from scratch  
6 transfer scratch commands into Thymio commands  
7 transfer thymio data to scratch  
8

# Evaluation

# Critical Reflection

# Appendices

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