Nottingham Trent University

School of Science and Technology

A New Form of Educational Logic Gate Simulator

by

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in

Software Engineering

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Abstract

This work introduces the use of logic gate simulators in educating students about the functionality of logic gates and how they come together to form circuits. It introduces existing methods on how this is accomplished. The report then goes on to investigate an apparently new design of logic gate simulator intended to educate students on logic gates, to an A-Level standard, more effectively. The new design, with its implementation described within the report, involves a challenge mode, in which teachers can create truth table to circuit and circuit to truth table conversion-based challenges for students. The challenge-based approach is intended to engage students in the ‘learning through reflection on doing’ process. This approach through means of user testing and observation has been deemed successful in that it provides students an alternative method to learn about logic gates, and evidence in this report shows that it may be more effective than previous approaches.

Acknowledgements

Enter acknowledgements here. It is usual to acknowledge those that have assisted you in your work and will normally include your main project supervisor. The order of acknowledgments (most important first) and their respective length indicates their relative importance to you.

Neil Sculthorpe ~ Tutor, review points, provided information relevant to report, overlooked project planning document ect…

Ferreira, Joao Filipe ~ Helped with formulating idea for new approach to logic gate simulator education

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Introduction

Introduction

### Scope

This report will focus as discussed in the abstract on a new design of logic gate simulator for educating A-Level students on the functions of logic gates. The new piece of software intends to target the issue discussed below and as a result provide a better means of educating students.

In order to get a better understanding of the topic at hand this report will delve into the general subject area surrounding logic gates and their education. This involves the areas of Computer Science, education techniques and various methods of educating students on logic gates.

### Relevance

Like why this is important….

## Background

Logic circuits are a fundamental part of all computer science related education programs. An understanding of these gates, how they come together to form circuits, and how these circuits are used is necessary for the successful study and implementation of the technological systems from which they are composed.

### Logic Gate Simulators

Logic gate simulators attempt to simulate logic gates and their behaviour when combined into circuits. They achieve this at varying levels of physical detail, such as at the transistor, gate, electronic system, or behavioural levels.

The primary use case for these simulators, especially those that are more complex, is for circuit design verification. By allowing users to directly interact with their designed model, they can see it in action without having to physically build it themselves. This dramatically reduces development costs as circuits only need to be built once users are assured the logic behind the circuits is functional to their requirements.

(Where they run ie. desktop)

(Maybe give some example of logic gate simulators here)

### Use of Logic Gate Simulators for Education

Using software as a teaching method.

Logic gate simulators can be used as an education tool to teach students the behaviour of gates and how they come together to form circuits. This report shall focus on logic gate education for A-Level students. From this perspective, features are usually from the gate/transistor level upwards.

Most of these tools make use of the experiential learning process, defined as ‘Learning through reflection on doing’ [1]. Various studies [2][3] demonstrate the effectiveness of the experiential learning process. These methods will be discussed further in detail within the context section of the report.

1.2.3.1 Recent Work

## Issues with Using Logic Gate Simulators for Education

Without a challenge or problem to overcome, getting students engaged in the learning process can prove difficult. Current logic gate education software tools fail to use challenge-based learning to achieve their goal. This is unfortunate, since challenge-based learning, based off-of experiential learning, is proven to be effective in engaging students in the learning process [4][5].

## Report Layout

A literature review will be performed within the context section of this report. Here, various other methods of logic gate education will be looked at. This review avoids accidentally repeating a technique that has been tried before ensuring that the method is entirely unique. The creation of this section will also aid in shaping the method and ensuring its validity.

The new ideas section of the document will outline the planning of the implementation of this new piece of software. This will outline the various stages of implementation and introduce some of the tools used in the process.

The design of the software will then be discussed within the implementation section. Here, the structure of the design will be explained so that readers can replicate the work. How the tools are used for the software will also be discussed here along with a display of the product itself.

Results and the overall success of the software on tackling the goal it set out to overcome will be discussed within the discussion section of the report. Finally, the report will be summarised within the conclusion section of the report.



CONTEXT

Introduction

The purpose of this section of the report is to review work within the general field of logic gate education. This avoids accidentally repeating a technique that has been tried before ensuring that the new method is entirely unique. The creation of this section will also aid in shaping the method and ensuring its validity. This is done though identifying gaps within existing approaches to logic gate education, showing the purpose of the new solution.

There are three main methods of logic gate education, many A-Level students are taught through a combination of these methods. Firstly, classroom theory usually from textbooks or their teacher. The other two methods involve putting their knowledge to use through practical engagement, physical experiments with electronic circuits and software simulations [xxx]. This literature review will investigate all three.

## Existing Solutions to Logic Gate Education

### Books or Online Research

Books are the main method of educating students on logic gates. Books, alongside teachers in classrooms, are used to teach students the theory of logic gates. Without the theory, engaging in experimental or practical based learning would be very difficult. This is because students require knowledge of the functions of logic gates before they can engage in using them.

Any A-Level computer science book should have theory information on logic gates and their functions. For example, Computer Science by Bob Reeves (<https://www.amazon.co.uk/AQA-level-Computer-Science-Reeves/dp/1471839516>). Students are usually given or requested to acquire these books when at school.



**Figure 1: Computer Science by Bob Reeves**

Students also make use of online resources for acquisition of theory knowledge of logic gates. As an example, khanacademy.org has all the information of basic functions of logic gates, enough for passing at A-Level. Both books and online resources also provide test questions, these allow for the student to see if they have correctly learnt theory.

While books and or online resources technically give students enough information for A-Level computer science logic gate knowledge, they do have downsides. On average people retain 25% of what they hear, 45% of what they hear and see, and 70% of what they hear, see and do. (Edwards 1985 ppp). These learning resources fail to make use of the ‘learning by doing’ education approach. As a result, learning using these methods is not as efficient as it could be. This study shows engaging students in some sort of practical exercise, in combination with initial theory would be greatly beneficial for them.

### Using Models

Module kits

There are many companies which sell logic gate modules for education, an example being Sphero Inc’s littleBits, figure 1 shows an example of one of their modules. (<https://classroom.littlebits.com/lessons/introduction-to-logic> picture from there to)



**Figure 2: A Sphero Inc’s littleBits Module**

The modules are individual gates which connect with other modules to form circuits. These companies attempt to offer a low-cost hands-on method for learning about logic gates. This method engages students in experiment-based learning a method proven, by many studies [yyy][zzz] to be effective within the classroom.

A paper on a proposal for a new system of 3D printable logic gates for students to learn about logic gates, demonstrates the validity of this method, as it shows research within the topic area is ongoing [fff].

Using module kits, while successful in part at educating A-Level students on logic gates, require theory in order to be used. Therefore, they act more as a supplementary aid in education, and cannot replace theory teachings.

Using a logic gate module kit for learning also does have its downsides as well. For instance, acquisition of the learning material must be done well before classes to ensure enough material exists for all students. While this material is low-cost it still does impact on education systems budgets. These modules are also physical, students may end up breaking, stealing or loosing them. Education using the modules is limited to within the classroom students taking them home would be impractical. Demonstrating the use of these in front of the class may prove difficult as well due to their small size. Students would need to huddle around the table on which they are being used. If the teacher is the only person to have the kit within the classroom then there is little benefit as compared to theory on a whiteboard. This would also not be making use of experimental-learning process.

A logic gate model board

An article on the creation of an E-Logic Trainer Kit explains the design as well as effectiveness of the prototype within an educational setting (<https://online-journals.org/index.php/i-joe/article/view/11410>). The abstract of the study outlines an overall positive response to evaluations, with 60% of the correspondence giving positive feedback.



**Figure 3: E-Logic Trainer Kit**

This model has similar teaching benefits to that of the module kits mentioned above, mainly that it engages students in experimental learning in a hands-on manner. However, it also shares the downsides of the model kits with the additional downside of its overall bulkiness.

### Simulator Software

There are various logic gate simulator software applications available. These fall into two main categories, those for education and those for circuit design verification. There is however some overlap. These simulators run on various platforms, as discussed below.

One popular open source logic gate simulator which runs on windows and mac OS computers, designed for education is Logisim (<http://www.cburch.com/logisim/>). This simulator is used by many schools and universities in classes ranging from GCSE Level to computer architecture courses. A conference paper investigated using Logisim as an educational tool [hhhh].

The results of a survey on the tool was in the paper. The average rating for all questions on the first part of the survey was 4.55 out of 5 (5=Completely agree, 4=Mostly agree, 3=Partly agree, 2=Mostly disagree, 1=Completely disagree), for questions relating to the effectiveness of the tool itself and in education. The second part of the survey was consisted of questions of a similar manner however asked in a more open-ended way. Nearly all the feedback within this section was positive, pertaining to “its effectiveness, system independency, and its ability to check and simulate the functionality of designed circuits using only a hand tool”.

From this survey it can be concluded that software simulators of logic gates are a very effective tool for practical learning of these gates. In many ways the software tools are a much better method of education than other practical engagement methods discussed above. Most simulator software is free, there are no limitations on the number of gates students can use. Circuits can be constructed and deconstructed much quicker and easier than physical education tool competitors. Demonstrations are much easier to perform within the classroom. Circuits can be setup, saved and returned to later. This method does require students to have computers, however in todays day and age, this is no longer much of an issue.

This article within the European Journal of Engineering Education also investigated the effectiveness of software simulators for educating students [uuu]. The abstract demonstrates similar results were concluded to that of the study conducted on Logisim.

Other platforms

Educational logic gate simulator software also reaches platforms other than those for just desktop/laptop computers. An article on the Web Based Interactive Digital Logic Circuit Simulator[qqq] is an example. The article itself has no survey results, however its existence is proof to a certain extent on the validity of such an approach. Mobiles can also be a target platform for these simulators, a conference paper done on the development of a logic gate simulator for mobiles[jfk] for education purposes demonstrates this. How effective this would be within an educational setting is up to debate given the limitations of phone hardware and students tendencies with distraction.

* Mention limitations of research, which is where you build off for your solution
* As a result of your literature review you should be able to elaborate on the limitations of existing methods of solution for your particular problem.



New Ideas

Introduction

This part of the report is to justify the new design based off an analysis of the weak points in the methods discussed within the previous chapter. This new design will then be outlined, and the planning that went into the project will be demonstrated.

As mentioned before, engaging students in the learning while doing process has been proven as a very effective method for educating them. However, without proper incentivisation for learning, students may not be as engaged as possible.

While textbooks and online resources do offer questions, they do not engage students in practical hands-on style problem solving, and instead demand theory style answers. The current methods of education aside from textbooks and online resources, fail to engage students in challenge-based learning. This is where justification for the new design begins to shine through. Challenge-based learning, based off-of experiential learning, is proven to be more effective in engaging students in the learning process [4][5]. Essentially, without challenges to overcome, students won’t find as much use in practical engagement with software/hardware models of gates since humans are goal-oriented thinkers. Usually to overcome this, teachers, books or online resources provide questions such as truth table to circuit and circuit to truth table conversion tasks.

Having the challenge mode within the new piece of software acts as a software solution for the providing of questions, which means students won’t have to refer to external sources for the questions, making the learning process more streamlined. As an additional benefit the “level” layout of the feature should engage students even more thanks to its game like style. This goal-oriented nature of the design means students are engaged in challenge-based learning as opposed to just learning while doing.

As a result of the analysis within chapter two it is obvious that a software implementation of this solution works much better than that of a hardware one. Firstly, the cost for students is free, thanks to no manufacturing cost for hardware along with no risk of losing or breaking components required for the teaching. Having the challenge part built into the software removes the need for paper. And the interface provides an easy method for teachers to construct the challenges for the students.

## Requirements

For the new idea to be achieved a piece of software has been created. This software had the following requirements set out during its creation.

* To model all logic gates taught in A-Level Computer Science classes, with the ability to link them together to build circuits. These gates should be placed, moved and removed from a “field” which the user should be able to pan over and zoom into.
* The ability to save and load previously made circuits and pages of circuits. This will be done through saving/loading “gatefield” files containing information of gates, locations and links between them.
* Provide a user-friendly graphical user interface. Interactions with gates and circuits and operations must be obvious to the user. This keeps the learning curve to a minimum and allows for a smooth learning process.
* The software must be robust in terms of performance. This will be ensured through unit and user testing.
* The software must have a challenge mode, in which teachers/students can create truth table to circuit and circuit to truth table conversion-based challenges for students. These challenges must be able to be saved/loaded as well as transferred between computers. The software must keep track of completed challenges.

How requirements relate to background research.

## Project Planning

Talk about ISO 1962?

### Methodology Used

The project was developed using the Agile software development methodology.

Describe agile.

### Deliverables

The development process was planned out before it began. The work was sectioned off into different deliverables to be completed by certain milestones. This was to balance the workload and ensure there was enough time to complete the project. Below are these deliverables.

1. Gate simulator with basic gates that are taught in education
2. Friendly UI method for selecting circuits to analyse
3. Generate a test framework for the gate simulator
4. Truth table / Karnaugh map / Boolean algebra / circuit conversion
5. Challenge mode functionality
6. Evaluation of the software – user testing
7. Completed dissertation

Below is a breakdown of the contents of these deliverables.

**3.3.2.1 Gate Simulator with Basic Gates**

The gate simulator acts as the base for the other software deliverables. It contains the main hub to be used to navigate to the various features of the software, along with the basic gate functionality, saving and loading features. Tasks to complete this deliverable include:

* Research programming architecture
  + Qt architectures
  + General architectures
  + Code style of existing logic gate simulators
* Research good educational aspects of existing simulators
  + Ask students & teachers
  + Review existing simulators
* Gates
  + Design images
  + Develop classes & functionality
  + Design links
* Design home page including:
  + Gate selection panel
  + Gate information panel
  + Design gate page class (Class to hold all gates on a page)
  + Operation buttons panel (Move, drag, break link, undo/redo, select, delete gate)
    - Design images
    - Develop functionality
  + Truth table to circuit dialog
  + Karnaugh map dialog
* Saving/loading
  + Develop loading class
  + Add save functions to gates & pages

**3.3.2.2 Friendly UI method for Selecting Circuits to Analyse**

Depends on: Deliverables 1

This deliverable consists of the tasks:

* Develop a gate selection class
  + Research into what makes a friendly UI
  + Develop class
  + Add on truth table & optimization functionality options (Not developed)
  + Add multi select

**3.3.2.3 Test Framework for Base Simulator**

Depends on: Deliverable 1

This was used in order to ensure correct functionality of the base gate simulator. Its tasks include:

* Choose testing framework system to use
  + Research into different testing frameworks
* Develop

**3.3.2.4 Challenge Mode Functionality**

Depends on: Deliverables 1 & 2. Tasks include:

* Developing a:
  + Challenge builder dialog for teachers
  + Challenge list saving capabilities
  + Challenge list loading capabilities
  + Challenge dialog for students
  + Results dialog for students & teachers
* Implement testing framework functions

**3.3.2.5 Truth table / circuit conversion**

Depends on: Deliverables 1, 2 & 4

The conversion deliverable is to achieve objective 3 (Provide the ability to convert both designed circuit types to truth tables. Along with conversion to and from truth tables, Karnaugh maps and Boolean algebra for combinational circuits). Its tasks include:

* Circuit to truth table conversion
* Truth table to circuit conversion
* Implement testing framework functions

**3.3.2.6 Evaluating the software**

Depends on: All deliverables (Excluding 7)

In order to evaluate the software, university students, who are already familiar with A-Level logic gate education, will be asked their opinions on the effectiveness of the software has on achieving it’s goal.

**3.3.2.7 Writing dissertation**

Depends on: All deliverables

### Milestones

|  |  |  |
| --- | --- | --- |
| Milestone | Date | Deliverables completed |
| Review Point 2 | 06/11/19 | 1 & 2 |
| Tutorial 3 | 20/01/20 | 3 & 4 |
| Tutorial 4 | 01/03/20 | 5 |
| Project submission | 24/04/20 | 6 & 7 |

### Workload Balancing

In order to keep workload balanced during development a gantt chart was created.

Gantt Chart

In order to meet the project outcomes, the following resources will be used:

|  |  |
| --- | --- |
| Resource | Reason |
| Laptop/desktop | Used to host the various software required for the project. |
| Qt creator IDE | Environment for developing the software required for the project. |
| QTest framework | Testing framework for testing the developed software. |
| Paint.net | Image editor for designing images of buttons & gates used in the simulator. |
| GitHub | Version control software which will act as a storage method for everything related to the project. Allows for saved iterations of the software & documents. |
| Notes document | To record relevant information about the project which may come in use later. |
| Timetable | To plan out work in a time managed manner. |

To conduct the project, the following sources of information are required:

|  |  |
| --- | --- |
| Information source | Reason |
| Qt documentation [6] | Documentation on the IDE & base library to be used to design the simulator. |
| Google | To be use for research into;   1. Programming architecture 2. Design styles 3. Testing frameworks   Also used as a method of accessing other information sources. |
| Competing software | By analysing competing software, a list of necessary components to be used in the core simulator can be derived.  Since not all competing software is freely available, there are some constraints as to the extent they can be analysed. To overcome this as best as possible the documentation and YouTube reviews of the paid software will be used. |
| Education websites & literature | Will provide information on exam style questions used for logic gate education to get a better idea on how to formulate the challenge designer. |
| Educators & Students | Will provide what works well & what features are missing in existing educational software.  Educators will also be used as aid for technically demanding areas of development. |

### Contingency Planning

(Alternative plans)

As a result of your 'Context' chapter you should have narrowed down your area of research. This 'focussing' of attention on one aspect of the field will have been aided by reading about other peoples' work in the field. You may be proposing a development of one of their ideas or perhaps an idea that came to you that differs from anything tried before.

For a software development you might include an explicit list of the requirements, a description of investigation of requirements ( if appropriate), and a discussion of how requirements relate to Background research.

For a research-based investigation you might include the planning for the process (methodology) to be adopted, the criteria to be used for evaluation, and a discussion of reasons for this process and comparison with alternatives.

The proposed development or investigation must be realistic bearing in mind the entire project is supposed to take 400 hours of your time. Thus, evidence of project planning must be included in this chapter; estimates of work load for the various phases, setting these in context with other estimated workloads (e.g. course work and revision) and other deadlines. This should allow you to establish your project timetable (perhaps in the form of a Gantt chart) showing the interaction of these various factors and the set objectives/milestones. In your planning you should include contingency planning to allow for the unexpected disaster. Various project planning tools are covered in the course to allow you to do this.

Discussion of platform of software. ?

JUSTIFY NEW IDEA



IMPLEMENTATION

Introduction

## Why GitHub

## Base Simulator Design

### Why C++

Tool used (ref), alernative tools (ref), why tool was chosen

### Why QT

Tool used (ref), alernative tools (ref), why tool was chosen

### GUI

4.3.3.1 Images

Tool used (ref), alernative tools (ref), why tool was chosen

### Code Core Design

4.3.4.1 Methods of Simulator Design

### Features

## Task Feature

### Development

### Result

## Unit Testing

### Benefits of Unit Testing

### Why QTest

Tool used (ref), alernative tools (ref), why tool was chosen

Here you give details of the development or investigation of the new material proposed in 'New Ideas'. This must be done in a business-like manner. The development of any software must follow a suitable analysis and design methodology. There are CASE tools available to you for some methodologies, others will have to be a 'paper' design. An investigation must also follow a suitable methodology and use appropriate techniques and tools.

Software-based projects, requiring the production of a software solution for a set of requirements, should demonstrate that the software development has undergone appropriate analysis, design, project management, structured programming and testing. Research-based projects, requiring an investigation of a research question or client’s requirements, or being used to test a hypothesis, should demonstrate that the investigation has been properly conducted, is based on scientific principles and uses appropriate tools, techniques and standards. An investigation must produce a technical outcome from some development (software or hardware (e.g. networks, displays)) or testing (e.g. of system/network performance, system security, HCI/usability analysis). Sometimes a software prototype or a testing framework will be produced for the evaluation or testing of the research or hypothesis. Work based purely on literature review is not acceptable.

Some projects aim to provide software for general use as their final product and these must include relevant aspects of HCI (Human Computer Interaction) and address such features of usability such as 'user friendliness' and most likely employ GUI (graphical user interface) standards such as Windows.

In any case, students often ask what should go in this chapter, how to describe what they have done, what is relevant, how much of existing work to include, what to include from what they have done, etc. The simplest and surest way is to refer to your diary of the work you have done and report on it in chronological order.

The complete requirements analysis, problem analysis & design of software must be done rigorously and included in full in an appendix. Avoid cross-referencing it too often, thus causing the reader to keep flicking pages back and forth, rather reproduce sections that you wish to draw the reader's attention to. That is, highlight the parts that you found particularly difficult to implement and feel rather proud of having solved. Do not include lengthy descriptions of standard techniques or methodologies, simply state that 'such-and-such was designed using such-and-such technique (give a reference, not just 'SSADM' but 'SSADM [James 1996]' where the reference is a standard text on the technique!)' and highlight where you found shortcomings in the technique that didn't quite cope with your particular problem. Highlight exceptions to the standard.



RESULTS / DISCUSSION

Introduction

The technique developed in your project is supposed to show improvement on techniques previously available. Therefore it may be necessary to spend time investigating whether this is true. Perhaps you need to set up some sort of quantitative test and do a little statistical analysis to confirm the improvement. This chapter will provide evidence, from the tests that you carry out, of the outcomes of your project.

Explain the success and limitations of your work and show how this relates to the aims and objectives set out in the introduction.



CONCLUSIONS / FUTURE WORK

## Conclusions

Whatever it was that your results showed should be summarised here. Your project or may or may not have achieved all that you set out to at the start.

This is your opportunity to conclude whether the project was a ‘success’ and how it might have been tackled differently in hindsight.

## Future work

In either case there should be some reference to future work, either to forward and expand on the successful outcome or to test ways of overcoming the shortfall in your ideas that didn't work out quite as expected but there should be something that shows you can see further implications of what you have achieved.

## Legal, Social, Ethical and Professional Issues

This section should include a discussion of the four LESPIs and the way in which you project has/will/could impact on each.

* Describe the four LESPI’s

Legal issues could be improved by considering relevant legislation, e.g. GDPR, Accessibility Legislation. Some points would benefit from more discussion, e.g. your intent to release the software as open-source (why are you doing this, what implications could it have?). For professional issues, you could look at a Code of Conduct from a professional body, e.g. BCS, and see if anything is relevant to the project.

During the research phase of the project, students and teachers will be interviewed on the features of logic gate simulators. In order to ensure this does not raise any LSEPIs, each interviewee with be given a participation consent form which they will sign. The form will outline what the interviewee will be subject to during the interview, the fact they will remain anonymous, as well as provide contact details so they can redact provided information later if they feel the need to do so.

A similar form will also be used during the evaluation phase of the project, in which interviewees will be asked to evaluate the software produced.

Once the software is published, it will be released as open source and free to download. Due to this it will be licenced with the MIT license.

When being used in the classroom if the software fails to emulate gates correctly, students may become misinformed on the interaction or properties of logic gates. To ensure any issues which arise because of this are covered, a declaration stating that the software may not be entirely accurate will be added to the release documents.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Legal issue | Social issue | Ethical issue | Professional issue |
| Interviews |  | X | X | X |
| Software release Licencing | X | X |  | X |
| Use of the software |  | X | X | X |

## Synoptic Reflections

This section will comprise of a reflection on the project in relation to employment aspirations and the skills that you have developed towards this through engagement with the project.

ReferenceS

Vogt, C. 1999. Creating Long Documents using Microsoft Word. Published on the Web at the Nottingham Trent University.

**Note:** References are a list that includes the essential bibliographical details for each item to which you have referred in the body of your paper. It should ONLY include items to which you have made direct reference. A direct reference is where you have quoted/reproduced text or diagrams from another author or mentioned/referred to the work of another author in your report. That is quoted directly what they have said about something or mentioned their views or conclusions in your report. For details of citation and references see the information in the Project Guide.

A Bibliography is a list of published materials that you have read or consulted for general information in the preparation of your work, concerning the subject of your Project, but have not made any direct reference to in your report i.e. 'background reading'.

You should always provide a Reference List. **A Bibliography is optional but when provided it should include all items in your Reference List as well as any additional items consulted in preparation of your work.**

Bibliography

Vogt, C. 1999. Creating Long Documents using Microsoft Word. Published on the Web at the Nottingham Trent University.

Coote, H., Dobbs, B. & Jones, C. (1996). Defining databases. Wiley: Melbourne.

Applications and Science in Soft Computing, Lotfi, Ahmad; Garibaldi, Jonathon M. (Eds.) 2004, X, 346 p. Springer, ISBN: 3-540-40856-8

**Note:** A Bibliography is a list of published materials that you have read or consulted for general information in the preparation of your work, concerning the subject of your Project, but have not made any direct reference to in your report i.e. 'background reading'.

You should always provide a Reference List. **A Bibliography is optional but when provided it should include all items in your Reference List as well as any additional items consulted in preparation of your work.**

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Appendix A

PUT USER DOCUMENTATION

The content of these will differ with the different types of project. Any design and analysis charts/diagrams will be included here in full. In projects where software has been developed there will be an appendix for this. Our departmental requirement is that a CD, DVD or USB memory stick of all source code is submitted to your project supervisor. The appendix contained in the report will refer to this CD, DVD, or USB memory stick, provide a directory style listing of the files submitted and instructions for rebuilding and running the software. This might be source code of programs written in high level languages (C, C++, etc) together with any pertinent files ('make' files, non-standard libraries, etc). Alternatively, or in addition, you can place some or all of the source code in the appendix. In any case the source code needed to reconstruct any software you have developed must be submitted in its entirety in the CD, DVD, or USB memory stick. (Any code that has been used from a third party should reference the original developer).

Hardware designs will require schematics/circuit diagrams, PCB layouts, simulation tests and pin outs.

Most projects will require some form of user documentation to explain how to use the software/hardware produced. A researcher following up the work may wish to utilise the work of the original author and an appendix laying out the format of input files and how to interpret the output is required.