

The Current State of Test-First vs. Test-Last Testing Draft

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ABSTRACT

When it comes to software development perhaps one of the most important and time consuming processes is that of software testing. In fact, early studies on software testing estimated that software testing could consume fifty percent or more of development costs for a product. Because of this, the ability to optimize testing to reduce testing costs can be very valuable. In this paper we compare two popular methods, test-last testing, often used in waterfall software development methods, and test-first testing, often used in Agile test driven development software development methods, by reviewing recent studies on the subject. In this review we discuss the possible benefits of test-first and test-last testing and possible problems with the current data comparing these two testing methods. After that, we explore other methods in test-first testing besides test driven development, such as behavior driven development, in an attempt to find a better test-first testing model. In the end we discuss our results and potential future studies to help clarify current data.

Categories and Subject Descriptors

H.4 [Information Systems Applications]: Miscellaneous;
D.2.8 [Software Engineering]: Metrics—*complexity measures, performance measures*

General Terms

Delphi theory

Keywords

ACM proceedings, L^AT_EX, text tagging

1. INTRODUCTION

When it comes to software development, perhaps one of the most important and time consuming processes is software testing. In fact, some early studies on software testing estimated that it could consume fifty percent or more of development costs for a product [1]. because of this, businesses

over time have become increasingly interested in attempting to optimize testing to reduce development costs.

Although there are many testing methods that currently exist, two particular testing methods are currently very popular: test-last testing and test-first testing. Test-last testing, used mostly in process oriented or waterfall development, is a testing method where testing is done after the software code has been written to ensure that the code works correctly. Test-first testing, used mostly in interval or agile oriented development, is a testing method where testing is done before the software code is written to ensure that the future code meets certain requirements.

Currently, there is much debate in the testing community about whether or not test first or test last testing is superior. The goal of this paper is to attempt to give an overview of the current state of this debate by analyzing current research data concerning the advantages and disadvantages of each of these testing methods. Because research often lags behind current implementations and the field of test-first testing is currently changing due to its relatively new implementation, this paper will also explore where new test-first methods are going and compare them to the research given. This paper will therefore discuss the advantages and disadvantages of test first testing versus test last testing and explore new emerging test-first methodologies in an attempt to determine the applicability of each methodology.

The rest of the paper is divided into four sections which will discuss the specific ideas above in more detail. In section two of the paper we will discuss what software testing is and current software development models with their supporting testing methods: test-first and test-last testing. In section three we will provide an analysis of the data explaining the potential advantages and disadvantages of test-first testing compared to test-last testing. In section four we will go over new test-first based testing methodologies and in section five we will state our conclusions and suggestions for further research in the field.

2. BACKGROUND

2.1 Software Testing

Software testing, simply defined, is a branch of software engineering that entails a series of practices meant to either identify potential malfunctions or demonstrate functionality in a software system [1]. Software testing can be as simple as running a program to see its results or can be as complex as writing code to simulate scenarios in the real world.

When it comes to judging the effectiveness of certain test-

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ing methods it is important to note that there is no one standard quantitative measurement. Because of this, many different types of measurement are used in an attempt to prove that one testing methodology is better than another. Although there are many different attributes that are used for arguing the superiority of one method over another, we will only focus on three attributes that are commonly found throughout research; code coverage, testing time, and code correctness. Code coverage refers to how many lines of code percent-wise are currently being tested. For example, if I write a test with 70% test coverage it means that 70% of the lines of code I wrote are being tested. Testing time simply means how long it takes to write the actual tests. Code correctness refers to how many errors are found within code after it is considered finished. These three attributes are popular to use because they can be quantitatively measured and are considered important within the testing community.

2.2 Waterfall Development and Testing

From as early as the 1970s a popular software development model was the waterfall model where software was developed in a series of phases. The waterfall method has been a popular development model because it is considered simple to implement correctly and is also considered to be time efficient because completing previous phases helps latter phases become more efficient. The first phase in the standard waterfall model was the requirements phase where requirements were set by the customer or design company. Next the design phase occurred where the product was designed which was then followed by the implementation phase where the product was actually created. The final phase of the development phase was then the verification phase where testing and debugging occurred [wikipedia waterfall model](#). Due to the fact that these processes often put testing at the end of development, a certain type of testing method, the test-last method, became very popular to use with the waterfall development method.

Test last testing is currently a popular testing method and is usually the first testing method that people tend to implement. Test Last testing is the practice of writing tests after code has been written to check the functionality of the written code. These tests are then used to check the written code for any potential errors which are then fixed by the developer until no errors are found by the tests. Test last testing is considered simple to implement and can allow the programmer to focus on writing tests based on areas of his code that he may be concerned about.

2.3 Agile Oriented Development and Testing

In the late 1990s some software developers started to criticize the sequence-oriented waterfall model, complaining that it was too brittle and inflexible to meet the demands of the standard customer. In response to these critiques of the waterfall model a new model for developing software emerged, the agile development model. This new development model, based on the tenets of the agile manifesto [cite manifesto here!](#), promoted the idea that all actions of development should not occur in an ordered sequence but in a series of time-boxed iterations where in each iteration setting requirements, product design, product implementation and product testing would occur simultaneously. The goal of each iteration is to produce a demonstrable working product to show a customer and receive feedback on the product. Some

current development practices that are considered agile are Extreme Programming and Scrum.

Due to the changes in Agile programming, test-last testing was pushed aside in favor of a different style known as test-first testing. In 1996 [might be 2001](#) with the release of the agile development practice Extreme Programming, the idea of test first testing, implemented in test driven development, started to become popular for the first time [2]. Test-first testing is the practice of writing tests before code has been written and then writing code to make the tests pass. It should be noted that since tests occur before development test-first testing tends to be heavily linked to development methods and thus the most common test-first models also include development elements as well.

The most well known and most used test-first model is that of test driven development or TDD for short. In its current use in the field, the phrase TDD is mostly used as a blanket term for any sort of development practice that uses test-first testing to drive code development. That being said it is important to note that although TDD has been turned into a vague term in this paper we will focus more on its original specific definition. [add more once we get to section 3](#)

3. RESEARCH DATA ON TEST-FIRST VS TEST-LAST TESTING

In this section we attempt to attempt to obtain useful conclusions between test-first and test-last testing by observing current research articles. In order to accomplish this we will first start with a data subsection that will go over the three main studies that will be used to draw our conclusions. Next we will have an analysis subsection that will summarize the results of the study in terms of our three main empirical measurements: code coverage, code correctness, and total development time. We will then have a discussion subsection that will take about potential issues with summarizing the data given in the research articles and then we shall proceed with a conclusion subsection where we will talk about potential conclusions we can draw from the data.

3.1 Data

In 2012 Lemos et. al [7] conducted a study on sixth semester students to see if test-first testing would increase code coverage, increase testing code size, increase code correctness, and/or decrease in total development time in auxiliary functions (functions with 10-200 lines of code) compared to test-Last testing. In this study 39 sixth semester students, knowledgeable in testing techniques and participants of two 100 minute long test first modules, were asked to complete coding challenges over two sessions. In the first session, half the students implemented testing-first testing while the other half implemented test-last testing to help solve the problem. In the second section the students were asked to switch roles and given a different coding challenge. In order to reduce domain knowledge bias amongst the coding challenges three different challenge question types were handed out at each session. The results of the study, which were analyzed for statistical significance using the Wilcoxon/Mann-Whitney non-parametric signed-rank paired test, found that test-first testing significantly increased code coverage, testing code size and code development time with no significant increase in code correctness.

In 2010 Kollanus [6] conducted a literary review of TDD. Using standard literary review methods, Kollanus found and reviewed forty different experiments in scientific journals, magazines, and conference proceedings that provided empirical evidence for TDD. In the review Kollanus found that the most used measurements in these experiments could be clumped into three measurements: external code quality, internal code quality, and productivity. In the study Kollanus observed that there was weak support for improved external code quality, very weak support for internal quality, and support for an increased amount of development time.

In 2012 Hellmann et. al conducted a summary on the current status of research of TDD. Within Hellmann's background there is a mention of a summary study produced by Jeffries and Mitnik that found in general that TDD largely resulted in an increase in quality, but one study they identified showed instead that TDD resulted in a strong negative impact on quality. Additionally while they showed that TDD could reduce the amount of effort required by up to 27%, most studies found an increase in effort of up to 100%.

3.2 Analysis

Two of the three studies covered the topic of code coverage. In both studies by Kollanus and Lemos et al. it was acknowledged that increased test coverage had occurred in test-first testing methods compared to their test-last counterparts. All three papers brought up up total development time and noted that test-first testing tended to increase development time, although both Kollanus's study and Hellmann's study provide notable contradictory studies to this conclusion. All three studies in one way or another also brought up code correctness in the form of external code quality in Kollanus or in the form of code quality in the case of Hellmann et al. In this case the results were across the board where Lemos et al. stated that there was no code correctness difference between test first and test last whereas Kollanus said there was weak evidence that test-first testing produces more correct code then test-last testing. Hellmann et al provided contradictory evidence backing that in most studies test-first testing has shown better code correctness then test last testing but there was a noted study where test-first testing was less code correct then test-last testing. In summary, with the studies given, test-first testing produces more code coverage and is likely to take more time to code then test-last testing but due to contradictions in the research given we can not draw a conclusion on code correctness.

3.3 Discussion

Many summaries of TDD research [2, 3, 5], including the literary review done by Kollanus [6], have noted that one confounding factor to their ability to summarize the research in the given field of test-first testing has been that many studies are contradictory to one another. For example in [3], there is a mention of previous summary studies that have had previous issues with conflicting data. This is then followed by a series of examples of data that has conflicted in other studies in the past. In Kollanus's literature review [6] Kollanus points out that many articles in her study contradicted other articles which made it hard to make sound conclusions from the research given and may be a confounding factor in her study. In most current studies this seems to occur because of two main factors: participant experience

and improper study implementation and documentation.

In the case of participant experience there seems to be a skill gap between test first and test last testing. In an opinion study by [4] it was found that a majority college students said they were not comfortable with and had trouble with comprehending TDD, even after doing a coding exercise with it. The majority of students also said that they were much more comfortable implementing test last methods and would prefer to use test last methods in the future. Coding professionals, on the other hand, actually preferred test first programming and were much more comfortable with it than students. They also stated they felt it was relatively easy to understand while students did not. In another opinion study [5], by Kettunen et al, a common theme throughout the paper was examples of individual testimonies and research conclusions that pointed to test first testing being harder to implement than test last testing. Considering that most conducted experiments focus on college students and industry professionals, who have vast experience differences, the fact that test first testing may be harder to implement for college students compared to industry professionals may create differing results between studies. This idea is considered in [2] and [5], but no summary papers were found considering this result and comparing student participant experiment results to professional participant experiment results.

The other problem that has plagued summary papers of test first testing is that most studies either lack documentation in key locations or do not effectively handle the participant conformance issue which comes up in TDD studies. In the literary review by Kollanus, she acknowledges a frustrating lack of information in many studies on how TDD was implemented. Most studies, claimed Kollanus, had maybe one or two lines describing their TDD methodology or just simply claimed that they used TDD. Considering that TDD can be implemented in many ways, as discussed earlier in the background, Kollanus states that the lack of documentation for TDD implementation means that, as a reviewer, she has no idea if the test methods used to produce the results were similar or different thus potentially confounding some of her conclusions. Another issue similar to this is the conformance issue, brought up in (cite here). The conformance issue in TDD testing refers to the fact that few researchers make sure that TDD was implemented correctly or at all by its participants. For example, in the study by Lemos et. al the researchers acknowledged that one of their confounding factors was that they only asked students to write tests before code, thus a variety of different test first methods might have been used within the study making its data less conclusive. Overall the lack of documentation of how researchers specifically planned to implement TDD in their study and their lack of some sort of monitoring of whether the implementation was actually occurring greatly reduces the credibility of the research being done and allows for confounding factors to potentially occur.

3.4 Conclusion

Due to current issues in contradictory data it is hard to make solid conclusions about the advantages and disadvantages of using test first testing instead of test last testing. What can be done instead is we can consider certain trends in research that can suggest potential answers. Most studies and summaries seem to agree that test-first testing tends

to produce more test coverage compared to test-last testing and that test first testing tends to take longer to write tests compared to test first testing. Two of the studies we looked at, the experiment by lemos and the literary review by Kollanus, point out these two trends. Also one or both trends have been noted through multiple papers [5, 2, 3] with no major contradictions found. Another convincing trend that has occurred is that in general test first testing seems to be harder to implement than test last testing as mentioned earlier. Although these trends seem to be clear, the rest seem to be more muddled. Code correctness for example seems to have no clear trend as multiple studies have reached contradictory conclusions to other studies. Another hot button topic that fails to show a trend one way or the other is the amount of time spent simply developing code as this again seems to have results across the board. From these trends we can consider that test first testing overall probably takes more time to write, increases code coverage, and is harder to implement than test-last testing and that other advantages or detriments may exist but they are unclear in current research.

4. EVOLUTIONS TO TDD

this section is currently a work in progress

As can be seen in the above sections there are some issues in the current implementation of TDD testing. Due to these issues new methods are starting to appear in the agile community that contain some of TDD's main tenets but have shifted enough away from TDD at some fundamental level that they are starting to receive their own names and classifications. Although there are many of TDD spin-offs, for this paper we chose to focus on three more popular spin offs, acceptance test driven development, Behavior driven development, and Agile Specification Driven Development.

4.1 Test Driven Development

Test driven development, as mentioned earlier is currently the most widely used test first testing and design methodology. Although in the previous cases we have been using TDD as a vague term in this section we will focus on the the original TDD methodology introduced in Extreme Programming. In the original TDD methodology the developer repeats a step of processes to develop his code. The process begins once all current tests pass or the new code has just been started. When this occurs the programmer writes a new failing test that tests the simplest functionality the programmer wishes to add to their code. Once the test has been written and the test fails, the programmer then writes the minimal amount of code to make the test pass. After this step the programmer proceeds to refactor any clutter within his solution and then repeats the process until the code is complete.

Although TDD is a very popular style of test first testing, it should be noted that a perceived weakness to the TDD methodology exists. The main issue many people have with test driven development is that it fails to suggest a style of testing and how to best define an independent functionality in ones code plan. In the study [5] (cite others here as needed) people noted that TDD was difficult because they had a hard time deciding how to implement their tests effectively. Another related issue noted in [5] was that some individuals found it hard to figure out what needed to specifically be tested thus some found they wrote an over-

abundance of tests causing the process to become inefficient and thus take more time. Others found that focusing on the simplest functions first left serious potential problems to the end of development causing a serious time crunch problem for product release. Due to these issues with defining functionality and other issues within TDD new methods for implementing test first testing are being designed and implemented in an attempt to solve these problems.

4.2 Acceptance Test Driven Development

Perhaps the closest spin off to TDD, acceptance test driven development (ATDD), follows many of the ideas and expectations that regular TDD does, like writing tests first and following and using tests to define the development code. Unlike TDD though ATDD believes that in order to produce higher quality code and better customer satisfaction customers should write or define "acceptance" tests that must be passed before the product is considered finished. This part of ATDD is noticeably different from the TDD ideology because in the TDD ideology only the developer should writes the tests and the tests should be written from simplest to hardest. [2]

Although some people claim ATDD is a step in the right direction for TDD developers their are also many people who have complaints about ATDD. One of the major complaints is that ATDD is an ideal practice at best because customers will not take the time to create useful acceptance tests. [2] Yet others state that ATDD is very hard for both customers and developers to implement correctly because their is no effective common language between the two factions.(site new IEEE article here) Because of these varied complaints some of the promoters of ATDD have moved away from it to support a newer similar TDD spin off, Behavior Driven Development or BDD.

4.3 Behavior Driven Development

BDD is a new spin off of TDD that focuses on how to correctly implement the fundamental usefulness of TDD. In BDD the most important thing that it argues is that TDD is unsuccessful because it is vague and it focuses more on "testing the code" then showing the codes behavior. Thus BDD argues that solving the problem is to stop thinking about code in terms of testing but to understand code in terms of behavior. Because of this shift in ideas BDD uses different testing tools, such as JBehave for java or cucumber for Ruby [8], compared to TDD that breaks code testing down into standard verbal sentences instead of basic testing language. The argued pros for this type of language usage is that it actually reduces much of the difficulty of tdd by allowing us to define the purpose of our code in more natural terms thus removing much of the confusion about what is important to test in TDD and the other pro is that now it is easier to communicate goals and functionality of the code to non computer science majors (IE Managers, Customers, Sales Reps, etc.) which allows for higher customer satisfaction. **this is just a blurb on BDD and what it is and what perceived advantages it contains, this paragraph will get reworked as it does not fit in the current paper well need to do more research here**

4.4 Agile Specification-Driven Development

The new testing style Agile Specification-Driven Development is a hybrid of two older testing styles TDD and DbC

(design by contract).

Advantage to merging the DbC system with TDD is it gives the designer a better idea about what is important to test **and other advantages should also crop up in research on DbC**

need to do research here, specifically it would be useful to do some research on DbC

4.5 section conclusion

the goal here is to have a discussion over which TDD spin off might be most promising and for what reasons

5. CONCLUSION

this section is currently a work in progress

5.1 Conclusion intro

In this paper we talked about two common test methods: test-first testing, often found in waterfall development models and test-last testing, often found in agile development models. In section two we defined these test methods as well as provided background information to the reader. In section three we explored recent research into the comparison of the two different testing methods and explored potential research problems with the current data. In particular we found that data was contradictory but we still were able to tentatively conclude that test-first testing increases test coverage, increases time taken to test, and is harder to implement than test-last testing. In this section we also suggested two potential reasons for the contradictory data: different participant experience levels and poor documentation/implementation of specific test first methods. In section four we explored different implementations of test first testing.

5.2 Discussion of Implications of Section 3

stubbed for now

5.3 Discussion of Implications of Section 4

stubbed for now

5.4 Suggestion for Further Research

For people who are looking to advance the field of TDD it would be potentially very interesting to see how the new TDD spin-offs such as Behavior Driven Development and Agile Specification-Driven Development compare to that of a well documented TDD process like the one suggested for Extreme Programming. Another useful study that could be implemented would be to compare the results of studies thing that could also help advance the field is to do research comparing the effectiveness of waterfall testing and TDD testing between groups with notably different experience levels as some research tentatively points that this may be a relevant variable.

This paragraph is a rough idea on the further research topic

conclusion brain storm

- TDD increases code test coverage
- TDD perhaps takes more skill to preform
- TDD may have more effective and less effective practices
- More study is needed.
- Better study methods should be implimented

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