Failure Rates in Introductory Programming Revisited

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ABSTRACT

Whilst working on an upcoming meta-analysis that synthesized fifty years of research on predictors of programming performance, we made an interesting discovery. Despite several studies citing a motivation for research as the 'high failure rates of introductory programming courses', to date, the majority of available evidence on this phenomenon is at best anecdotal in nature, and only a single study by Bennedsen and Caspersen has attempted to determine a worldwide pass rate of introductory programming courses.

In this paper, we answer the call for further substantial evidence on the CS1 failure rate phenomenon, by performing a systematic review of introductory programming literature, and a statistical analysis on pass rate data extracted from relevant articles. Pass rates describing the outcomes of 161 CS1 courses that ran in 15 different countries, across 51 institutions were extracted and analysed. An almost identical mean worldwide pass rate of 67.7% was found. Moderator analysis revealed significant, but perhaps not substantial differences in pass rates based upon: grade level, country, and class size. However, pass rates were found not to have significantly differed over time, or based upon the programming language taught in the course. This paper serves as a motivation for researchers of introductory programming education, and provides much needed quantitative evidence on the potential difficulties and failure rates of this course.

Categories and Subject Descriptors

K3.2 [**Computer and Information Sciences Education**]: Computer science education

General Terms

Measurement, Experimentation, Verification.

Keywords

Introductory Programming, CS1, Programming, Pass Rate, Failure Rate, Statistics

1. INTRODUCTION

The demand for skilled programmers is increasing on a global scale. Recent projections from the United States Bureau of Labour Statistics [11] suggests the growth of computing careers is set to continue through 2020, and that various computing skills will be in strong demand for the foreseeable future. To address these future labour demands, governments throughout the world are in the process of bringing programming into the classroom environment, so that students can be better prepared to work within a digital economy. From September 2014, UK schools will replace the Information and Communication Technology (ICT) course with Computing. Pupils aged 5-7 will be expected to understand "what algorithms are" and how to "create and debug simple programs". Ordinary classroom instructors are naturally concerned about the proposed changes. A recent poll showed that 74% of current ICT teachers do not believe they have the right skills to deliver the new computing curriculum, and fear that they do not have the time to learn the new skills required [5].

This is perhaps not surprising, as learning to program can be an incredibly difficult task, to the point where the phrases "failure rate" and "programming course" are almost synonymous [2]. For instance, [3] states: "*Substantial failure rates plague introductory programming courses the world over and have increased rather than decreased over the years*". Although high failure rates are an often cited motivation for research into programming education, only a single paper to date [2] has attempted to provide quantitative evidence to support this claim. This is problematic, and a lack of hard facts on the outcomes of introductory programming courses (henceforth called CS1) can have implications for both instructors and students. Instructors of failing CS1 courses may accept their shortcomings as "that's just the way programming courses are". Likewise potential students may be easily put off taking the course to start with, which will not help future labour demands to be satisfied.

In this paper, we expand the work of [2] by performing a systematic review of introductory programming literature, in an effort to statistically consolidate further quantitative evidence on the often cited worldwide high failure rates of programming courses. The contributions of this paper are:

1. Verify the findings of Bennedsen and Caspersen.
2. Demonstrate that failure rates in CS1 have not significantly improved over time.
3. Explore possible moderators of failure rates, including: country, grade level, language, and cohort size.

2. RELATED WORK

Although many researchers have cited high failure rates as an off the cuff motivation for CS1 research (e.g. [3, 8, 10]), only Bennedsen and Caspersen [2] have attempted to provide quantitative evidence on this phenomenon. Around 2005/6, [2] sent a short survey to the authors and panel participants of five CS educational conferences: Koli Calling '04, ICALT '04, ACEC '04, SIGCSE '05 and ITiCSE '05. The survey was designed to collect data on the outcomes of the CS1 courses at the respective researcher's institution. A total of 63 usable responses from researchers in 15 different countries were received, representing a response rate of 12.3%. The main findings of their study were:

1. A worldwide pass rate of CS1, estimated to be 67%, however large variations in the pass, fail, abort, and skip rates were reported.
2. Smaller classes (< 30 students) are suggested to have a higher pass rate than larger ones (82% vs 69%).
3. Colleges are suggested to have a higher pass rate than universities (88% vs 66%).
4. The pass rates would seem to be independent of the language taught (objects-orientated vs imperative).

However there were several limitations of the study which we attempt to address in this work. Firstly, the work of [2] provides a useful snapshot of the state of CS1 education, but only at a single point in time. A more interesting analysis would be to examine whether the pass rates of CS1 have improved over time, possibly in response to the introduction of more advanced pedagogical techniques and tools, such as game-based learning techniques [15], or improvements to the compilation feedback provided by novice IDE's [12].

Secondly, the authors acknowledge that their sample size may be insufficient to make generalized conclusions to CS1 courses worldwide. Only the outcomes of 63 courses taken from 62 different institutions were used, and it is perhaps interesting to consider why 87.7% of contacted authors failed to respond. One possibility is that the non-responding authors had higher failure rates than they wished to report, and therefore did not respond. This would mean that the worldwide pass rate of CS1 could be lower than [2] reported.

Thirdly, although researchers from 15 different countries responded, the sample of 63 responses was heavily dominated by institutions from the United States. 66% of responses came from US institutions, with the remaining 14 countries providing (mainly) 1-2 responses each. This limitation again makes generalization of the findings on CS1 pass rates to a worldwide scale difficult.

Fourthly, the findings were based upon a survey that was only sent to the authors at five conferences on CS education. This is a narrow target group, and inevitably omits a great deal of evidence on pass rates that remains unexplored, published in the proceedings of other conferences and journals. By exploring this additional source of data, a fuller picture on the worldwide outcomes of CS1 courses can be identified.

In short, there is still a need to further examine and analyse quantitative evidence on the outcomes of CS1 courses on a worldwide scale. This can only benefit the research community as a whole, as the more quantitative evidence that is available on CS1 outcomes, the more solid motivation can be used for further research into CS1 education.

3. RESEARCH DESIGN

Whilst the work of Bennedsen and Caspersen [2] was based upon surveying the authors of selected conference papers and performing a statistical analysis of the responses, our work is based upon performing a systematic review of the literature on CS1 education, and performing a statistical analysis of the data extracted from relevant articles.

3.1 Research Questions

To answer the call of [2] by expanding their work, our research questions were defined as follows:

1. What are the pass and failure rates of introductory programming courses? Are these high figures?
2. How do the pass and failure rates of introductory programming courses compare over time?
3. Are the pass and failure rates moderated by any of the following aspects of the teaching context:
   (a) Country
   (b) Programming language taught in the course
   (c) Size of the class
   (d) Grade level of the institution

3.2 Data Collection Method

The motivation for this work arose whilst we were working on an upcoming meta-analysis which synthesized fifty years of research on predictors of programming performance. As such a proportion of the data we have used for our analysis on the failure rates of CS1 was extracted from articles identified while we conducted the meta-analysis. Supplementary searches were then conducted to identify additional data.

3.2.1 Initial Search

In an attempt to identify every study that examined predictors of programming performance, a search of all articles published between the years 1960 - June 2013 was carried out. Initial electronic searches were made of the following databases, repositories, and websites: (1) ACM, (2) IEEE, (3) Science Direct, (4) Wiley Online, (5) Taylor & Francis, (6) JSTOR, (7) SAGE, (8) PsycNET, (9) EThOS, (10) ProQuest, (11) DART, (12) Trove. Following this, further general searches were made using (1) Google Scholar, (2) ISI Web of Knowledge, (3) ERIC, and a final search was conducted by manually screening the indexes of selected conference proceedings and journals for relevant studies.

Keywords were identified by two researchers. A boolean strategy using the operators AND and OR refined the searches ensured that an exhaustive search was conducted. Specifically the search criteria used was: (Predict OR Predictors OR Predicting OR Identifying OR Indicators OR Influence OR Factors OR Traits OR Tests OR Relationship) AND (Performance OR Aptitude OR Ability OR Success OR Training OR Achievement OR Outcomes OR Learning) AND (Programming OR Programming Course OR Introductory Programming OR CS1).

1378 articles were identified. After applying an inclusion screening based on abstract and full text content, a sample of 58 articles that examined predictors of programming performance remained. Only 12 of these articles provided quantitative data on the failure rates of their respective CS1 courses, and these were extracted for analysis in this study.

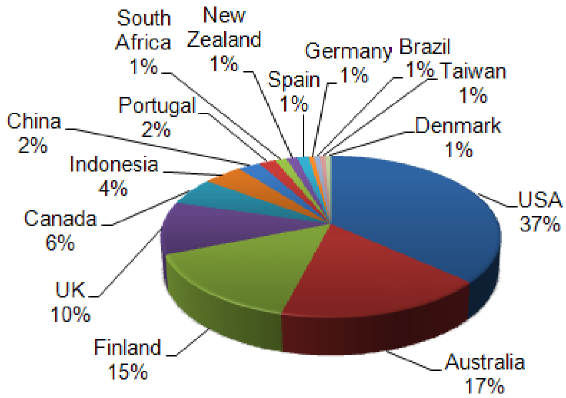

Figure 1: Geographical distribution of the outcomes

3.2.2 *Secondary Search*

As our meta-analysis focused upon a narrow area of CS1 research (predictors), it was necessary to conduct supplementary searches to identify other articles that provided quantitative evidence on the pass rates of CS1. We believed that an abundance of such data would be available from articles that described interventions designed to improve the performance of CS1 students. As such, the initial search process was repeated, but with the following search criteria: (Pass Rate OR Failure Rate OR Success Rate OR Withdraw OR Completion OR Dropout OR Improving) AND (Programming OR Programming Course OR Introductory Programming OR CS1). This resulted in the identification of an additional 42 articles after screening that provided pass rate statistics of the CS1 courses at their institutions.

3.3 Description of the Sample

After verifying that the same failure rate had not been coded twice (e.g. reported in two articles), the resulting sample consisted of 54 articles: 37 conference, 11 journal, 3 theses, 2 unpublished, and 1 book chapter. The sample described the outcomes of 161 CS1 courses that ran between the years 1979-2013, although the majority of outcomes (80%) were for courses that ran from 2003 onwards. The outcomes included in this sample were from 51 different institutions, across 15 different countries. The geographical distribution of the outcomes used in this study are shown in Figure 1. To compare our sample to the one used by [2], our sample was less dominated by a single country. In the sample used by [2], 67% of outcomes were from US institutions whereas in our sample, 63% of outcomes came from 14 countries. US institutions contributed 37% of the outcomes, followed by Australia 17%, Finland 15%, and UK 10%.

4. RESULTS

4.1 Pass and Failure Rates of CS1

The first question addressed by this study was to determine the average pass rate of CS1 courses, and to verify whether or not the 67% pass rate found by Bennedsen and Caspersen [2] was accurate. Figure 2 shows a distribution of the 161 pass rates used in this study, alongside the pass rates reported by [2]. As can be seen from this figure, the pass rates used in this study followed a normal distribution (Shapiro Wilk test, $p > .05$). The proportions of each

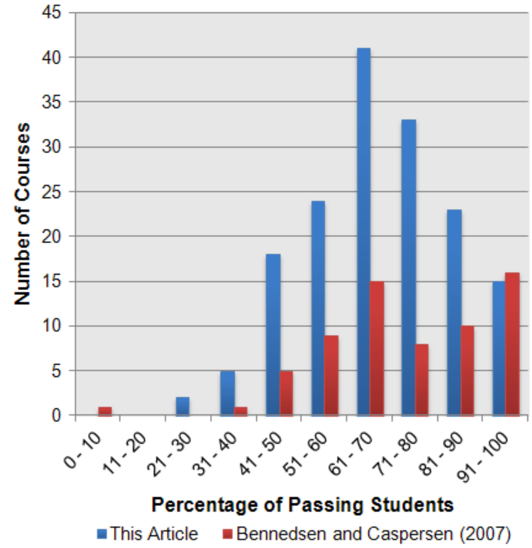

Figure 2: Pass rates of the 161 CS1 courses compared to the findings of Bennedsen and Caspersen.

pass range were similar to the ones reported by [2], with the modal pass range being 61-70%, and the majority of pass rates (61%) concentrated in the range of 50-80%. As can be seen, the pass rates varied considerably, ranging from a low of 23.1% to a high of 96%.

The mean CS1 pass rate found by this study was 67.7% (95% CI: 65.3% to 70.1%), which is practically identical to the 67% figure reported by [2]. Whilst it is debatable whether or not, a sample based on the outcomes of only 161 CS1 courses across 15 countries is representative of the worldwide state of CS1, when this finding is considered in conjunction with the similar result found by the independent [2] study, an average CS1 pass rate of 67% may be close to the mean figure across other countries.

The natural question which follows is what happens to the remaining 32.3% of students who do not pass? Disappointingly, individual breakdowns on the failure and withdraw rates of courses were difficult to come by, and only 36 fail rates were explicitly stated as such. Analysing this data only, a similar mean pass rate of 66.9%, and mean failure rate of 30.3% was found, with the remaining 2.8% presumably representing withdrawals and non-completions. Whilst these figures are comparable to the results on the complete sample, and we can state that 32.3% of students did not pass CS1, we cannot say what the exact reason for this was.

4.2 Pass and Failure Rates Over Time

The second question addressed by this study was to determine whether or not, the pass and failure rates of CS1 have changed over time. Grouping the 161 pass rates by the year in which the course was run, a one-way ANOVA was performed. There were no outliers in any of the groups, as assessed by the inspection of a box plot. The pass rates were normally distributed for each year, as assessed by Shapiro-Wilk test of normality ($p > .05$), and homogeneity of variances was confirmed by Levene's test ($p = .108$). A one-way ANOVA showed that there were no statistically significant differences in pass rates of CS1 for any of the years covered by this study, $F(21, 139) = .486$, $p = .971$.

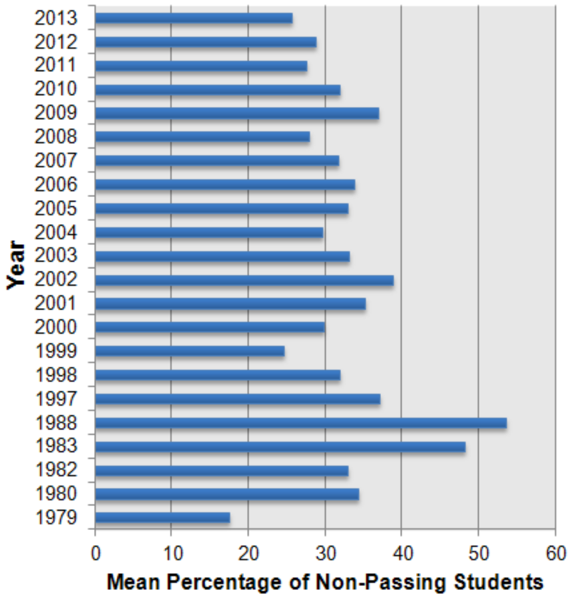

Figure 3: Non-passing students by course year.

As can be seen from Figure 3, the mean percentage of non-passing students has remained constant throughout the 2000's, and similar rates can be seen during the 1980's and 1990's. The percentage of non passing students by year ranged from 53.5% to 17.4%, and 67% of years covered by this study had a pass rate of between 67% and 75%. Given the increased amount of tools available to support CS1 students, it is interesting to see that there have been no significant improvements in the pass rates of CS1 over time.

4.3 Pass and Failure Rates by Moderators

The third question addressed by this study was to determine whether or not any aspects of the teaching context (country, programming language taught in the course, size of the class, grade level) moderated the overall pass rates.

4.3.1 Country

It is well known that educational practices and assessment criteria can vary across different continents. Therefore the first moderator we considered was whether or not the pass rates of CS1 differed by the country the course was taught in. Grouping the 161 pass rates by the 15 countries that were previously presented (Figure 1), a one-way ANOVA was performed. The previously stated assumptions were satisfied, and a Shapiro Wilk test confirmed the pass rates were normally distributed for all countries ($p > .05$), with the exception of Canada ($p < .05$). However as violations from normality do not substantially affect the type I error rate, and an ANOVA is considered relatively robust against this violation, we proceeded. Levene's test confirmed the homogeneity of variances ($p = .15$), and a one way ANOVA revealed significant differences in the pass rates of CS1 by country, $F(14, 146) = 4.58$, $p < .001$.

From Figure 4 it can be seen that the mean percentage of non-passing students varies considerably by country. Portugal was found to have the lowest mean pass rate ($\bar{\mu}_{pass} = 37.9\%$), followed by Germany ($\bar{\mu}_{pass} = 44.7\%$), and Brazil ($\bar{\mu}_{pass} = 45\%$). But, these findings were based on a small sample, and cannot be generalized. In terms of the 4 countries which made 80% of the sample, Finland was found to have the lowest pass rate ($\bar{\mu}_{pass} = 57.7\%$) and the pass rates of the USA ($\bar{\mu}_{pass} = 70.9\%$), UK ($\bar{\mu}_{pass} = 69.3\%$), and Australia ($\bar{\mu}_{pass} = 68.3\%$) were not found to be statistically different. We hypothesized that on larger samples, the pass rates for each country would tend towards a similar range, as was the case with our largest 4 groups.

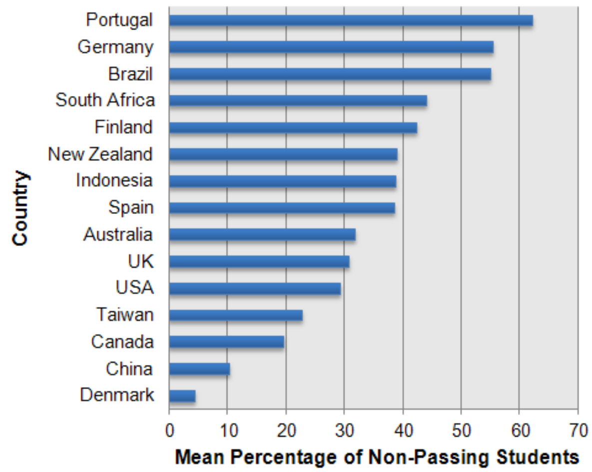

Figure 4: Non-passing students by country.

4.3.2 Programming Language

There has been much debate among CS educators as to which programming language should be taught to students first (e.g. adopting an objects-first or imperative first approach [4, 6]). We next examined whether or not the pass rates of CS1 differed by the programming language that was taught in the course. Pass rates were grouped into 9 categories, as follows: C (4.3%), Python (10.6%), C++ (6.8%), Java (46.6%), VB (1.9%), Fortran (1.9%), Novice (Scratch, Karel, 6.2%), Others (Standalone, 8.1%), and Not Stated (13.7%). An ANOVA was performed. The previous assumptions were satisfied, and a Shapiro Wilk test showed that the pass rates were normally distributed for all languages ($p > .05$), apart from Python ($p < .05$). The variances were heterogeneous (Levine's test, $p < .05$), and a Welch ANOVA showed no significant differences in the pass rates of CS1 by language, Welch's $F(8, 18.74) = 1.26$, $p = .31$.

In Figure 5 it can be seen that the mean percentage of non-passing students does not vary considerably by programming language. The percentage of passing students appears to be lower for C (61.1%) and C++ (56.2%) however the differences are not significantly different to the other languages whose pass rates are in the range 65% to 75%. This result is consistent with the work of [2] who also found no significant differences in pass rates based upon the language taught.

4.3.3 Class Size

As the size of a class has a natural impact on the level of support that a student receives, we explored it as a third moderator. Class size data was only available for 101 (62.7%) of the courses included in our sample. To verify previous work, we replicated the binary classification used by [2].

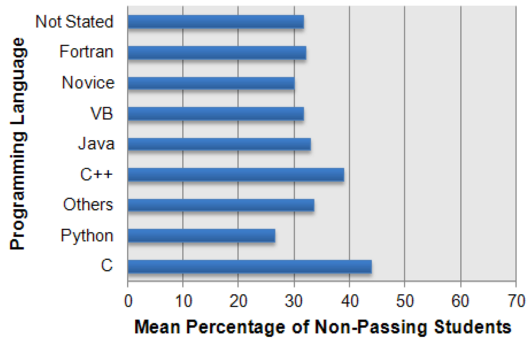

Figure 5: Non-passing students grouped by language

Classes were defined as small if they consisted of < 30 students, and large otherwise. A Shapiro Wilk test showed that the pass rates were normally distributed for both small and large classes ($p > .05$), and that variances were heterogeneous (Levine's test, $p < .05$). An ANOVA showed significant differences in the pass rates of CS1 by class size, Welch's $F(2, 27.23) = 6.78$, $p < .01$. The results on our sample for small classes ($\bar{\mu}_{pass} = 80.1\%$, $SD = 11.4$) and large classes ($\bar{\mu}_{pass} = 65.4\%$, $SD = 16.7$) confirm the findings of [2], who found higher CS1 pass rates for smaller classes, than larger classes (69% and 82% respectively).

4.3.4 Grade Level of Institution

Finally, we explored whether there were any significant differences between the pass rates of universities and other educational institutions (colleges, high school). Our sample consisted of 145 university courses and 16 from other institutions. An ANOVA was performed. A Shapiro Wilk test showed that the pass rates were normally distributed for Universities ($p > .05$), but not for other grade levels. Homogeneity of variances was confirmed by Levene's test ($p = .20$), and one-way ANOVA revealed significant differences in the pass rates of CS1 by grade level, $F(1, 159) = 11.62$, $p < .001$. The results on our sample for universities ($\bar{\mu}_{pass} =$, 66.4%, $SD = 15.3$) and other grade levels ($\bar{\mu}_{pass} = 79.9\%$, $SD = 11.9$) confirm the findings of [2], who found the pass rates for universities to be lower than other institutions.

5. DISCUSSION

The findings of this study confirm the results of the small study conducted by Bennedsen and Caspersen [2]. As shown in Table 1, this study found an almost identical pass rate of CS1 courses of 67.7%, and comparable results were found based on course size, and institutional grade level.

The additional contributions of this study have been to show that CS1 pass rates vary by different countries, have not improved over time, and they are largely unaffected by the programming language taught in the course. The question which arises from these findings is that if external aspects of the teaching context do not have a substantial moderating effect on the pass rates of CS1, then which internal characteristics of certain students enables them to acquire programming skills whilst others endlessly struggle? However, recent studies have suggested that despite over fifty years of research, we still do not know precisely which characteristics influence their ability to acquire programming skills [14] and possibly the programming behaviours of student may have the strongest influence on their performance [13], and in turn, the failure rates of CS1.

Table 1: Comparison of Results.

	This Study		Bennedsen [2]	
Pass Rate	Courses	Pass %	Courses	Pass %
Overall CS1	161	67.7	63	67
Colleges	16	79.9	12	88
Universities	145	66.4	50	66
Small Class	10	80.1	15	82
Large Class	91	65.4	48	69

Until such characteristics can be identified, the implication from this study is that the best approach for teaching CS1 may be based upon small groups, and replacing traditional lectures with classroom based instruction. This ties in with research on small group teaching, and the use of pair programming to improve performance [9].

5.1 Are the Pass Rates of CS1 Low?

When considering the average pass rate found by this study, we share the sentiments of [2], in that 67.7% is not an *alarmingly* low pass rate. On the other hand, when considering this figure within the wider context of CS education, we have a different view. Enrolment and retention of CS majors are well known problems [1]. Within the UK for instance, statistics provided by the Higher Education Funding Council show that out of all STEM degrees, Computer Science is the only subject where enrolment has consistently declined between the academic years 2001/2002, and 2011/12. A decline in enrolment numbers from 67,896 to 45,158, or 33% [7]. Although showing improvement in recent years, the number of students studying American institutions has also declined to half that it was in 2000 [16].

Part of this decline may stem from the reputation of Computer Science, or to be precise CS1, of being a difficult course. As CS1 is usually one of the first subjects taught to students taking a CS degree, it forms a benchmark of their impressions of the entire discipline. If the pass rates of CS1 are perceived to be low, then attracting students will undoubtedly prove problematic.

On the other hand, if pass rates can be improved, then the reputation of CS1 will in turn be improved. This may lead to an increase in enrolment numbers, and possibly increased retention. Currently we have found in this study 3/10 students do not complete, or fail CS1. If an estimated 2 million students are currently enrolled worldwide in computing courses worldwide [2], then an improvement in the pass rate of only 5%, would lead to an additional 100,000 students graduating with the skills required to satisfy the future labour demands that were outlined at the start of this article. Therefore while we do not believe that a 67.7% pass rate is *alarmingly* low, we also believe that there is considerable potential for improvement.

5.2 Threats to Validity

Whilst the sample of outcomes used by this study was over double the size of the sample used by [2] (98 more outcomes), it is still debatable as to whether or not it is representative of CS1 courses on a global scale. [2] reported that in 1999, there were over one million students enrolled in computing courses across 72 different countries. In this paper, we were only able to identify outcomes from 15 different countries, which means that we lack data from the majority of the countries in the world. Only by collecting such data can our results be further validated to a worldwide scale. On the other hand, when considering the results in conjunction with the findings of [2], our findings are consistent, and therefore may be close to the actual results in the population.

The second threat to validity concerns the sources of the data used. Whilst [2] surveyed authors of selected conference papers and panel attendees directly via email, our data has come from a systematic review process. It is possible that the data used by [2] was already published in the articles that we have used in this study, in which case, 63 of our articles may represent data that has already been analysed by earlier work. However we believe this is unlikely, as 83% of our sample came from articles published during a different time period to the authors contacted by [2], and only 2 articles were included from the conferences that their authors were selected from. Also whilst [2] was based entirely on *grey* literature, ours was based entirely on published works. It is possible that our results may suffer from publication bias - as there may be a reluctance among authors and institutions to publish high failure rates, and the actual pass rate of CS1 may be lower than our study has indicated.

The final threat to validity concerns the assessment criteria of the individual courses that have been included in this study. Studies within the UK generally defined 'pass rate' as consisting of those students who had scored over 40% in the course. However, other studies defined pass rate as consisting of those students who had scored at least a 'C', and others defined pass rate as consisting of those students who had scored anything apart from an 'F'. Other studies did not supply details at all. Therefore this study unavoidably has to assume that a consistent notion of pass rate exists and holds valid across the different teaching contexts.

6. CONCLUSION

There is a tendency among CS1 researchers to generalize high failure rates as a motivation for work. In this paper, we answered the call of [2] for further substantial evidence on the fail rate phenomenon by performing a systematic review of introductory programming research, and a statistical analysis on the data extracted from relevant articles.

An almost identical mean worldwide pass rate of 67.7% was found. Moderator analysis revealed significant, but perhaps not substantial differences in pass rates based upon: grade level, country, and class size. However, pass rates were not found to have significantly differed over time, or based upon the language taught in the course. The question which follows from these findings is that if external aspects of the teaching context do not have a substantial moderating effect on the pass rates of CS1, then which internal characteristics of certain students enables them to acquire programming skills whilst others endlessly struggle?

The limitation of this study is the sample size. Whilst the sample was over double the size of the one used by [2], 161 pass rates is still a relatively low number. But as two independent studies have both found a mean CS1 pass rate of 67%, it is possible this is not too far away from the figure in the population (estimated 65.3% to 70.1%). Whilst we did not find the pass rate of CS1 to be alarmingly low, we do conclude that there remains scope for improvement.

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APPENDIX

Due to space limitation, and to serve as a starting point for future researchers, a list of articles that were used in the analysis of this study have been made available in the following document: http://bit.ly/1iJdBSz