Programming aptitude and learning success in the introductory course on programming

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Abstract:

It is difficult to learn to program. We investigated if it is possible to predict programming aptitude of our students with Dehnadi-Bornat test early in order to give more attention to the students which are identified as less apt for programming. We present the results of the test and the correlation of test results and the final marks of courses of programming in the paper. We found out that the Dehnadi-Bornat test is appropriate for our students. We also present didactical models that have been used in teaching of computer programming in our courses.

1 Introduction

Learning to program is very difficult for many students and many of them fail the introductory programming courses. We investigated if there is any test that can early predict their programming aptitude and consequently success in the examination at the end of the course.

First year students of Computer science at the Faculty of Education have their first programming course on Pascal in the second semester. After teaching this course for several years we found out that many students have problems with learning to program. The results from exams show that only about 60% of students pass this course in the first attempt.

We decided to use the Dehnadi-Bornat test for our investigation. Dehnadi and Bornat claim that they had found a test for programming aptitude which can early predict success [1].

In the paper we describe the Dehnadi-Bornat test and we explain how we have used it for our investigations. We present the results of our students participating in the Dehnadi-Bornat test and we correlate them with their final marks in the course. In section 4 we describe different didactical models that were used for teaching programming.

2 Dehnadi-Bornat test

Our research started with investigation if there is any test that can early predict success in examination at the end of the programming course. Dehnadi and Bornat from Middlesex University claim that they had constructed a test for programming aptitude that can early predict success [1].

With this test we detect mental models that students use when they think about assignment instructions and short sequences of assignments in programming languages. Students complete the same test twice, at the very beginning of their course before the students are taught about assignment and sequence, and then the second time after the topic has been taught [3]. It was expected that novices would display a wide range of mental...
models, and that as time went on students which successfully learned to program would converge on a ‘correct’ mental model that corresponds to the implementation in programming language [3].

Dehnadi-Bornat test consists of 12 questions. Each question gives a sample Java program, declaring two or three variables and executing up to three variable-to-variable assignment instructions [2].

Dehnadi devised 11 different mental models labeled from M1 to M11 that are anticipated mental models of assignment (Table 1). According to the results in Dehnadi-Bornat test, students are divided into three groups:

- consistent group (students used the same mental model for 80% of questions)
- inconsistent group (students used different mental models)
- blank group (students refused to answer almost all questions)

<table>
<thead>
<tr>
<th>Table 1: Anticipated mental models of assignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1. Value moves from right to left (a←b and b←0)</td>
</tr>
<tr>
<td>M2. Value copied from right to left (a←b)</td>
</tr>
<tr>
<td>M3. Value moves from left to right (b←a and a←0)</td>
</tr>
<tr>
<td>M4. Value copied from left to right (b←a)</td>
</tr>
<tr>
<td>M5. Right-hand value added to left (a←a+b)</td>
</tr>
<tr>
<td>M6. Right-hand value extracted and added to left (a←a+b and b←0)</td>
</tr>
<tr>
<td>M7. Left-hand value added to right (b←b+a)</td>
</tr>
<tr>
<td>M8. Left-hand value extracted and added to right (b←b+a and a←0)</td>
</tr>
<tr>
<td>M9. Nothing happens</td>
</tr>
<tr>
<td>M10. A test of equality</td>
</tr>
<tr>
<td>M11. Variables swap values</td>
</tr>
</tbody>
</table>

Students can be classified in four different levels of consistency (Figure 1). C0 is most consistent level and C3 is least consistent level.

Any C level can be considered as subject’s level of consistency if:

\[
\text{Mode value in C level} \geq \text{abs (no. of answered questions * 80%)} \quad \text{and} \quad \text{no. of answered questions} \geq \text{abs (no. of questions * 80%)} \quad [3].
\]

In [1] Dehnadi and Bornat stated: “In the total population 32 out of 61 (52%) failed; in the first-test consistent group only 6 out of 27 (22%). We believe that we can claim that we have a predictive test which can be taken prior to the course to determine, with a very high degree of accuracy, which students will be successful.”

In [2] they reported that after six experiments, involving more than 500 students at six institutions in three countries, the predictive effect of our test has failed to live up to that early promise. From the results of the experiments reported in [2] it seems that the test does not give expected results if the students are already experienced.
Despite these results we decided to use the test for our students. Main reason for this decision is that the majority of our students does not have any prior programming knowledge (73% of students in generation this year) and therefore our population is appropriate for Dehnadi-Bornat test.

3 Method

First year students of Computer science at the Faculty of Education, University of Ljubljana were included in our investigation. These students have their first programming course on Pascal in second semester. 30 students participated in our experiment and 22 students did not have any prior programming knowledge.

Students completed the first test in the first week before any teaching of programming. First test was filled-in by 38 students. We collected also some information about their age, sex and previous programming experience in the test. Students completed the second test during the course, after they were taught about assignment and program control sentences (e.g. if-sentence and loops). Second test was completed by 30 students. Our students learn to program in Pascal so we had to adapt Dehnadi-Bornat test. Java programs in the test were replaced with Pascal programs.

According to the results in Dehnadi-Bornat test students were divided into three groups, consistent, inconsistent or blank group. Only students who were consistent in level C0 (i.e. they had use the same mental model for at least 80% of questions) were classified in consistent group.

The goal of our investigation was to confirm the hypothesis that final mark of the course is correlated with results on Dehnadi-Bornat test.

4 Results

4.1 Classification of students according to Dehnadi –Bornat test

40% of the students were consistent in level C0, 47% were inconsistent and 13% were blank in the first test. In the second one, 80% of students were consistent in level C0, 17% were inconsistent and 3% were blank. As majority of students were consistent, we decided to remodel the groups for classifying students. First group consists of students that were consistent in level C0 and chose correct mental model of assignment in Pascal (i.e. model M2). We designate this group “C0-M2”. Second group consists of students that were consistent but their mental model was not M2 (group “C0”). Third group consists of students that are consistent in level from C1 to C3, inconsistent or blank (“Other”).

After the first test, 17% of students were in group “C0-M2”, 23% of students were in group “C0”, and 60% of students were in group “Other”. The results of the second test were the following: 50% of students were in group “C0-M2”, 30% of students in group “C0” and 20% of students in group “Other”. Presented results include students with previous programming experience as well as students with no previous programming experience.

We also investigated the distribution in the case where only students with no programming experience were selected. 22 students with no programming experience represent 73% of all participating students. After the first test, 14% of students were in group “C0-M2”, 23% of them were in group “C0” and 64% in group “Other”. After the second test 45% of students were in group “C0-M2”, 32% in group “C0” and 23% of them in group “Other”. These results are slightly different from the results in the case where students with and students without programming experience were included.
4.2 Correlation of Dehnadi-Bornat test results with final exam results

As we have already mentioned, was the goal of our investigation to confirm the hypothesis that final exam results are correlated with results on Dehnadi-Bornat test which classifies students into groups according to the mental model they use when thinking about assignment. We tested correlation with \( \chi^2 \) test. If conditions for \( \chi^2 \) test were not fulfilled, that is more that one fifth of expected frequency in contingency table were under 5, the correlation was tested with Likelihood ratio test. When the correlation is statistical significant we used Phi coefficient which calculates degree of association.

As we can not expect that students would choose the correct mental model that corresponds to the assignment in Pascal on their first test, that is before they had any lesson on programming, we investigated if students, who were consistent after the first test, were more successful on the final exam. Results show that 77% of students that were consistent on first Dehnadi-Bornat test passed final exam and 23% of them failed. Other students who were inconsistent or blank were mainly unsuccessful on their final exam, 75% of them failed. The correlation is significant by the \( \chi^2 \) test (\( p \leq 0,009 \)). There is less than 9‰ chance that correlation between results on first Dehnadi-Bornat test and results on final exam are coincidental. We also calculated degree of association between these two variables with Phi coefficient (\( \Phi = 0,519 \)). Based on calculated Phi coefficient we can say that there is moderate correlation between results on first Dehnadi-Bornat test and results on final exam.

If we consider students with and with no prior programming knowledge separately, we get results shown in Table 2 and Table 3. For students with no prior programming knowledge we see strong correlation. 83% of consistent students passed final exam and 89% of other students failed. The correlation is significant by the Likelihood ratio test with \( p \leq 0,004 \). Phi coefficient (\( \Phi = 0,753 \)) shows strong correlation. For students with prior programming knowledge correlation between consistency and results on final exam is not significant.

| Table 2: Consistency against pass/fail results for students with no prior programming knowledge |
|---|---|
| pass | fail |
| consistent | 83% | 17% |
| other | 11% | 89% |

| Table 3: Consistency against pass/fail results for students with prior programming knowledge |
|---|---|
| pass | fail |
| consistent | 71% | 29% |
| other | 67% | 33% |

After the second Dehnadi-Bornat test, which students completed after they were taught about assignment and program control sentences in programming languages, we expected from successful students to use the correct mental model for assignment in Pascal, that is model designated M2. We tried to find out if students in group “C0-M2” were more successful in the final exam than other students. The results show that 82% of students in group “C0-M2” passed the exam and 90% of students in group “Other” failed. The correlation is significant by the \( \chi^2 \) test with \( p \leq 0,001 \). Phi coefficient of 0,718 indicates strong correlation.

Similar are the results for students with no prior programming knowledge (Table 4). In group “C0-M2” 71% of students were successful in their final exam and 88% of students from group “Other” were not. Likelihood ratio test shows significant correlation with \( p \leq 0,016 \) and Phi coefficient (\( \Phi = 0,612 \)) shows moderate correlation. There is even stronger correlation for students with prior programming knowledge (Table 4). All of the students in group “C0-M2” passed final exam and all students in group “Other” failed. According to the Likelihood ratio
test, the correlation is significant with $p \leq 0.006$. Phi coefficient is 1 that means absolute correlation.

**Table 4:** $\chi^2$ and Likelihood ratio test for correlation between second Dehnadi-Bornat test and final exam

<table>
<thead>
<tr>
<th>experienced</th>
<th>Value</th>
<th>df</th>
<th>Asymp. Sig. (2-sided)</th>
</tr>
</thead>
<tbody>
<tr>
<td>no Pearson Chi-Square</td>
<td>5,402$^a$</td>
<td>1</td>
<td>.020</td>
</tr>
<tr>
<td>Continuity Correction$^b$</td>
<td>3,225</td>
<td>1</td>
<td>.073</td>
</tr>
<tr>
<td>Likelihood Ratio</td>
<td>5,786</td>
<td>1</td>
<td>.016</td>
</tr>
<tr>
<td>N of Valid Cases</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>yes Pearson Chi-Square</td>
<td>6,000$^c$</td>
<td>1</td>
<td>.014</td>
</tr>
<tr>
<td>Continuity Correction$^b$</td>
<td>2,344</td>
<td>1</td>
<td>.126</td>
</tr>
<tr>
<td>Likelihood Ratio</td>
<td>7,638</td>
<td>1</td>
<td>.006</td>
</tr>
<tr>
<td>N of Valid Cases</td>
<td>6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- a. 4 cells (100.0%) have expected count less than 5. The minimum expected count is 2.80.
- b. Computed only for a 2x2 table
- c. 4 cells (100.0%) have expected count less than 5. The minimum expected count is .67.

Based on presented results we can say that Dehnadi-Bornat test can early predict programming aptitude and success on final exam for students with no prior programming knowledge. Correlation between results on first and second Dehnadi-Bornat test with results on final exam is significant and Phi coefficient indicates strong and moderate correlation. For students with prior programming knowledge the correlation between results on second test and final exam results is significant but correlation between first test and final exam is not. 67% of students with prior programming knowledge that were not consistent on first Dehnadi-Bornat test passed final exam. These students probably did not take Dehnadi-Bornat test seriously and thus the results showed that they are not consistent.

We also investigated if there is any correlation between results on Dehnadi-Bornat test and scored points on final exam. For determining the correlation we used the point biserial correlation coefficient ($r_{pb}$).

Firstly we calculated $r_{pb}$ for results on first Dehandi-Bornat test and scored points on final exam of all students, with and with no prior programming knowledge. Correlation is not significant. If we consider only students with no prior programming knowledge the $r_{pb}$ is 0.71 that means the correlation is strong. Correlation is significant with $2p \leq 0.01$. $r_{pb}$ of -0.23 for students with prior programming knowledge is not significant.

Point biserial correlation coefficients for results on second Dehnadi-Bornat test and points on final exam are the following. $r_{pb}$ for all students is 0.64 and indicates moderate correlation and is significant with $2p \leq 0.01$. Correlation for students with no prior programming knowledge is also moderate ($r_{pb}=0.57$) and significant with $2p \leq 0.05$. Correlation for students with prior programming knowledge is not significant.

We can say that results indicates that students with no prior programming knowledge who were consistent on first Dehnadi-Bornat test and were consistent with correct mental model on second Dehandi-Bornat test scored higher points on their final exam. For students with prior programming knowledge we can not make this assumption.
5 Didactic models for teaching programming

Teaching programming at the faculties of education is based on comprehension of the programming language syntax, study of semantics, algorithmic thinking, skill of programme writing, learning from examples, “problem solving”, programming in the group and teaching programming [4].

We used a combination of the following models in our course:

- **Semiotic ladder** is based on the language-like features of programming languages. The teaching and learning sequence starts out from syntax, proceeds to semantics and continues to pragmatics of the language-like tools. Its rationale is that syntactical knowledge is needed to express anything, and therefore it should precede the learning of meaning of the language constructs. When the meaning is known, the students can start to learn how to use language for specific purposes, which is the pragmatics.

- **Cognitive objectives taxonomy** has used a teaching strategy that resembles Bloom’s taxonomy of cognitive objectives. The sequence of instruction comprised using an application program, reading the program, and changing the program. “Creating a program” activity may also be added. This model is suitable for future computer science teachers because it implicitly explains the meaning of algorithms.

- **Problem solving** is strongly motivated by the constructivists’ view of how learning occurs. “Through solving problems, the students should extend their experience and repertoire of practice, and the basis for the process is the knowledge structure of the field of programming. The problem solving process is guided by methods and environments. Compared to the previously mentioned approaches, this one stresses the input and outcome of the learning process in terms of knowledge and personal behavior.” There has been a four-stage problem-solving process developed that has been used to teach computer science. First, try to understand the problem by structuring, dividing, clarifying, and finding sample Input/Output. Second, design a solution by finding related problems and solutions and checking the related solution against the sample Input/Output. Then, write the final solution by completing and adapting the found solutions to the problem. Finally, review the solution by testing it and summarizing what has been learned.

Using these didactic models, we wanted to help those students who were identified as less apt for programming on first Dehnadi-Bornat test. With appropriate combination of the above mentioned models we wanted to increase the number of students using the correct mental model (i.e. M2) in the second Dehnadi-Bornat test.

6 Conclusion

Learning to program is a difficult process for students and many of them do not pass the introductory course on programming. This was the reason for our investigation if it is possible to predict early programming aptitude of our students with Dehnadi-Bornat test and give more attention to those who are identified as less apt for programming. We used the test despite finding that the test does not give expected results if the students are already experienced. Computer science students at the Faculty of Education mainly have no prior programming knowledge and are therefore appropriate for this test.

The results of our investigation confirmed that Dehnadi-Bornat test can be used for early prediction of programming aptitude and of success on final exam in the introductory course on programming for students with no prior programming knowledge.
We can confirm that with results that we got correlating results on Dehnadi-Bornat test, which classifies students into the groups according to the mental model they use when thinking about assignment. Test is not appropriate for students with prior programming knowledge. Correlation of results on second Dehnadi-Bornat test and final exam results is significant but correlation of first Dehnadi-Bornat test and final exam is not. We can confirm what was reported in [2]: it seems that the test does not give expected results if the students are already experienced.

Appropriate use of didactic models presented in section 4 gave good results. In the first Dehnadi-Bornat test 40% of students were consistent and 17% of students used correct mental model M2. After the second test 80% of students were consistent and 50% used mental model M2. 39% of students that were inconsistent or blank in the first test used correct mental model in second test.

In our case Dehnadi-Bornat test gave good results. For our population with no prior programming knowledge, the test predicted correctly student’s programming aptitude. We plan to use this test for the future generations of our students.

References:

www.cs.mdx.ac.uk/research/PhDArea/saeed/paper1.pdf


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