Enhancing statistical literacy
Marianne van Dijke-Droogers¹, Paul Drijvers² and Jos Tolboom³

¹Csg Prins Maurits, the Netherlands; m.j.s.vandijke-droogers@uu.nl
²Utrecht University, the Netherlands; p.drijvers@uu.nl
³SLO, the Netherlands; j.tolboom@slo.nl

Abstract: Current secondary school statistics curricula focus on procedural knowledge and pay too little attention to statistical reasoning. As a result, students are not able to apply their knowledge to practice. In addition, education often targets the average student, which may lead to gifted students missing challenge. This study explored ways to enhance grade 8 (Pre-University level) students’ statistical literacy through within-class differentiation. The developed course materials consisted of a differentiated module in the Digital Mathematics Environment (DME), combined with investigation activities during classroom sessions. The material focused on statistical reasoning using visual representations made with TinkerPlots. We concluded that this teaching arrangement indeed increased students’ statistical literacy.

Keywords: Statistical literacy, descriptive statistics, Digital Mathematics Environment, level differentiation, TinkerPlots.

Introduction

Statistical literacy has become important for all of us, and statistics will only continue to become more critical in the future (Shaughnessy, 2010). Despite the global effort to innovate the ways in which statistics is acquired, current statistics education is still viewed as a field with a need for significant improvement (Garfield & Ben-Zvi, 2008). Strong educational foci on methodological skills, procedures and computations result in the limited ability to reason statistically and to apply statistics in practice (Allen et al., 2010; Gal, 2002).

The Netherlands are no exception to this. In grade 8 of the Dutch pre-university stream, for example, the statistics curriculum stresses the calculation of mean, modus and median. Statistical investigation and use of technology hardly occur in the current approach. The emphasis on calculating statistical measures contributes insufficiently to interpreting, critically evaluating and reasoning with data (Van Streun & Van der Giessen, 2007).

As a second concern, the current educational approach pays too little attention to gifted students. PISA research shows that the best quartile of Dutch students performs relatively poorly (Kordes, Bolsinova, Limpens & Stolwijk, 2013). It is plausible to assume that the education received is insufficient for these students. This is endorsed by the KNAW (2003), which calls for more differentiation between students and for offering enrichment material.

To address the abovementioned issues this study focuses on the following key question: Does a differentiated learning trajectory that focuses on statistical reasoning with visual representations increase students’ statistical literacy in grade 8? The hypothesis is that an educational approach in which differentiated online tasks are combined with investigation activities in class will increase statistical literacy.
Theoretical framework

The theoretical framework we used integrates notions of statistical literacy and level differentiation.

Statistical literacy

Gal (2002) defines statistical literacy as interpreting, critically evaluating and reasoning with statistical information. This requires, in addition to procedural statistical skills, reasoning with and about data (Tolboom, 2012). Students should be taught the necessary skills to interpret and reason with statistical concepts. Research indicates that students in an early stage can reason meaningfully about distributions (Bakker & Gravemeijer, 2002). According to Piaget and Inhelder (1951), students have an intuitive sense of statistical reasoning. This intuitive concept can be used to develop statistical literacy. Moreover, research literature suggests that students become statistically literate by conducting their own research projects (Abel & Poling, 2015).

Web-based tools like TinkerPlots (Konold & Miller, 2011), which focus on the use of dynamic visualizations, may support statistical reasoning and literacy. The use of such software, in addition to manual data processing experiments, has the advantage that problems are taken care of, so there is more room for reasoning. There is evidence that the use of ICT in statistics can improve learning results (Morris, Joiner & Scanlon, 2002) and, especially if embedded in classroom discussions, can lead to increased statistical literacy (Bakker, 2004).

Based on these findings, we focus in this study on literacy and reasoning using digital tools.

Level differentiation

The Dutch education system\(^1\) is based on homogeneous streaming. Nevertheless, within a class of a specific achievement level, major differences between students in intelligence and performance may exist. Students’ learning progress may suffer from neglecting these differences. In differentiated teaching, teachers provide individual learning paths to students, adapted to their levels, to learn as much as possible (Tomlinson, 1999). That level differentiation leads to better academic performance in primary education (age 4-12) has been shown by several researchers (e.g., Vernooy, 2009). With respect to differentiation in secondary education (age 12-17), less is known, even if Terwel (1988) and Van Dijk (2014) suggest that differentiation within mathematics lessons may lead to improved performance.

Differentiation assumes the classification of students. The RTTI model (Drost & Verra, 2015) can be used to identify the cognitive level of a learner. Dutch secondary schools and textbook editors increasingly use this model. It is based on four learning levels: Reproduction (R), Training (T1), Transfer (T2), and Insight (I). Based on RTTI test scores, the students can be clustered into level groups (Berben & Teeseling, 2014). In terms of the RTTI model, statistical literacy relates to T2 and I levels. Based on the aforementioned findings, in this study we opted for a differentiated educational approach based on the RTTI learning levels.

Methods

We successively describe the design, intervention, participants, data collection, and data analysis of the study.

Design research

Since teaching materials that aim at increasing the statistical literacy by offering differentiated teaching arrangements and using digital tools for this group hardly existed, we used a design research method (Bakker & van Eerde, 2015; Plomp & Nieveen, 2013). Because the learning objectives differ from the current curriculum in grade 8, no control groups were used; we compared the students’ learning gains during the intervention through pre- and post-tests. This research can be characterized as a "proof of concept" of an intervention that focuses on statistical literacy and reasoning through a technology-rich, differentiated approach based on RTTI.

Intervention

The intervention consisted of statistics modules within the Freudenthal Institute's Digital Mathematics Environment (DME, see www.dwo.nl/en), combined with investigation activities during the classroom sessions using Tinkerplots. The DME is a digital environment in which students work on mathematical activities. It includes opportunities for differentiated education by offering several learning routes. The work of students is saved in the DME and teachers can monitor the results (Bokhove & Drijvers, 2012). In this study the procedural skills, e.g., calculating central tendency and variation measures and values of various graphs including boxplots, were offered within the DME. The DME modules were individually run and consisted of two learning routes: the basic route and the plus route. The students were assigned to these conditions according to their RTTI achievements during the past schoolyear. Students with average score T2 and I less than 65% followed the basic route, and others the plus route. Within the designed DME modules, students could check their work and correct it when necessary. Adjacent to each classroom session, students worked at home on the DME module. The hypothesis was that the procedural skills of students will strengthen through the DME-modules, so that they can use them in reasoning with statistical information.

Statistical reasoning in the frame of investigation tasks was central to the eight 60-minute classroom sessions offered in parallel to the DME modules. During this classroom sessions students worked in homogeneous teams (clustered according to the RTTI learning levels). The investigation activities were based on the stages of the statistical investigation cycle (Franklin et al., 2005). The students analysed their data manually and by using the software TinkerPlots (Konold & Miller, 2011). This software provides rich visualization.
opportunities, flexible and investigative functions, and is user-friendly. Figure 1 shows some examples of the visual possibilities in TinkerPlots. The hypothesis was that clustering of students while working on investigation activities and using visual representations in TinkerPlots, sharpens and reinforces the statistical literacy of students at the different levels.

**Participants**

In the pilot the designed material was tested in a classroom at the school of the researcher, the Csg Prins Maurits in a rural area in the Netherlands. The pilot class consisted of 25 pre-university grade 8 students (14-15 year olds), with sixteen students turning out to be basic students and the other nine plus students. The students had no previous experience with statistic education.

**Data collection and data analysis**

To verify whether the intervention improved statistical literacy, we examined students’ DME progress, results on two statistical tests, logbook data from the teacher-researcher and students’ final investigation task. The data of basic and plus students were analysed separately. To analyse the DME work we used data on score and time investment. Further to the DME modules two individual tests were taken. One of these tests was a RTTI standardized test conducted with 45% of questions at learning level R and T1 and 55% of questions at level T2 and I, the latter corresponding to statistical literacy. This ratio is in line with the standard approach in the research class, so the results can be compared with previous RTTI scores on math tests. The additional test consisted of questions at learning level T2 and I with a higher difficulty compared to the RTTI standardized test, so as to obtain additional information about the level attained.

The logbook of the teacher-researcher contained information about students’ progress in interpreting, critically evaluating and reasoning with statistical information during the investigation activities in class. To find out whether the students in the end applied the statistical methods in practice, a final investigation task was administered in homogeneous level groups of 3-4 students. A rubric was developed for the analysis of this task to assess performance at learning level T2 and I.

<table>
<thead>
<tr>
<th></th>
<th>DME data</th>
<th>RTTI test</th>
<th>Test at T2 and I</th>
<th>Log</th>
<th>Research task</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statistical literacy in solving concrete problems</td>
<td>X</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Statistical literacy in investigation activities</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

**Table 1: Table of triangulation of research instruments**

To ensure the quality of the research data triangulation is used. Table 1 shows how the statistical literacy has been measured with multiple instruments. The font sizes for x indicate the degree to which each instrument measures statistical literacy.

**Results**

We now present the results of the learning process using the DME, the test results and the development during the investigation tasks.
Learning process using the DME

Average time investment per DME module in minutes (sd)

<table>
<thead>
<tr>
<th></th>
<th>Mod. 1</th>
<th>Mod. 2</th>
<th>Mod. 3</th>
<th>Mod. 4</th>
<th>Mod. 5</th>
<th>Mod. 6</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic students</td>
<td>36(21)</td>
<td>30(13)</td>
<td>36(19)</td>
<td>39(21)</td>
<td>27(14)</td>
<td>33(29)</td>
<td>34(20)</td>
</tr>
<tr>
<td>Plus students</td>
<td>42(28)</td>
<td>25(16)</td>
<td>30(27)</td>
<td>37(23)</td>
<td>19(16)</td>
<td>21(22)</td>
<td>28(22)</td>
</tr>
</tbody>
</table>

Average score per DME module in percent (sd)

<p>| | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic students</td>
<td>87(9)</td>
<td>81(23)</td>
<td>80(13)</td>
<td>79(16)</td>
<td>70(30)</td>
<td>53(31)</td>
<td>75(24)</td>
</tr>
<tr>
<td>Plus students</td>
<td>79(24)</td>
<td>91(8)</td>
<td>72(27)</td>
<td>61(33)</td>
<td>65(37)</td>
<td>43(35)</td>
<td>67(32)</td>
</tr>
</tbody>
</table>

Table 2: Time investment and score using the DME

The investment of time and scores of the DME work for each level group and per module are summarized in Table 2. The students used the DME with an average time investment of more than half an hour per session. During the learning trajectory the time investment, in particular for the plus students decreased. Initially, the students needed extra time for getting acquainted with the material. Moreover, the students indicated that over time they thoughtfully chose their way through the module by skipping known problems.

The students’ scores on the DME show an average of about 70%. The basic and plus students respectively achieved an average score of 75%(24) and 67%(32) per module. The exercises in the plus route were more difficult. The scores decreased during the learning curve when difficulty increased. In the last module there is a substantial decline. This module contains no new material, but includes joint exercises from the completed chapters. The plus students show more variability in score. The considered choices in learning exercises by these students might have strengthened this trend.

Test results

Table 3 provides an overview of the pre-test score (RTTI average score on nine math tests over the past schoolyear) and post-test score (RTTI score on the final statistics test). The RTTI pre-test scores indicate the achieved learning level of the students at the end of each chapter. This means that based on the presented pre-test scores the expected RTTI post-test scores should be on average 55% at the levels T2 and I. However, the RTTI post-test scores

<table>
<thead>
<tr>
<th></th>
<th>Whole class (n=25)</th>
<th>Basic students (n=16)</th>
<th>Plus students (n=9)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre av.</td>
<td>Post</td>
<td>Pre av.</td>
</tr>
<tr>
<td>Score on R and T1 in percent (sd)</td>
<td>79 (16)</td>
<td>85 (10)</td>
<td>79 (13)</td>
</tr>
<tr>
<td>Score on T2 and I in percent (sd)</td>
<td>55 (18)</td>
<td>64 (21)</td>
<td>47 (16)</td>
</tr>
</tbody>
</table>

Table 3: RTTI scores before and after the intervention
reached on T2 and I, the parts that measure statistical literacy, show a 9% higher score of 64%. The dissimilarity in progress between the basic students (12%) and plus students (4%) at the levels T2 and I may be caused by a ceiling effect or maybe the exercises in the RTTI standardized test gave too little space to plus students to exhibit their knowledge.

On the additional test both level groups exhibit a high score on T2 level, in spite of the increased difficulty. A smaller increase appears on learning level I. The results cannot be compared with previous tests because the difficulty of the conducted questions was considerably higher.

Learning process during investigation activities

The usual statements of students’ written work at the start of this intervention can be characterized as short answers with a calculation of the mean. The used visual representations were limited to bar and pie charts. Figure 2 shows students’ work on the first investigation task: Investigate the colour composition of a bag of M & M’s. In the final investigation task the students’ work contained detailed descriptions and rich visualizations with a wide diversity of graphs. Attention was paid to the interpretation of the data.

Learning progress was visible in terms of interpreting, critically evaluating and reasoning with statistical information. Figure 3 shows a small part of students’ work on the final investigation task in which they formulated and investigated their own research questions using datasets within TinkerPlots. The results on the final investigation task with respect to learning level T2 (65% of the total score) and I (35% of the score) are shown in Table 4.

<table>
<thead>
<tr>
<th></th>
<th>Whole class (n=8)</th>
<th>Basic groups (n=5)</th>
<th>Plus groups (n=3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Score on T2 in percent</td>
<td>89 (7)</td>
<td>85 (6)</td>
<td>95 (4)</td>
</tr>
<tr>
<td>Score on I in percent</td>
<td>51 (24)</td>
<td>35 (6)</td>
<td>79 (10)</td>
</tr>
<tr>
<td>Total score in percent</td>
<td>70 (26)</td>
<td>60 (27)</td>
<td>87 (11)</td>
</tr>
</tbody>
</table>

Table 4: Scores on T2 and I at the final investigation task
On level T2, for example, we evaluated in the assessment-rubric correctly representing and summarizing the data and on level I we examined the choice of an appropriate visual representation and the critical interpretation of the results. In comparison to the basic groups, the plus groups show a higher score on learning level I. This investigation task probably provided more room to gifted students to exhibit their statistical reasoning.

**Conclusion and discussion**

The main question in this research was: Does a differentiated learning trajectory that focuses on statistical reasoning with visual representations increases students’ statistical literacy in grade 8? The results suggest it does. The RTTI scores reached on T2 and I, the parts that relate to statistical literacy, were much higher than would be expected according to the pre-test scores. Moreover, the final investigation task showed strong progress on interpreting, critically evaluating and reasoning with statistical information according to the start of this trajectory. This is consistent with the theories by Bakker & Gravenmeijer (2002) and Abel & Poling (2015) on developing statistical literacy. Both basic and plus students showed considerable improvement during the learning trajectory which suggests that both groups were challenged in this differentiated approach as suggested by Terwel (1988) and Van Dijk (2014). The use of all kinds of visual representations within TinkerPlots helped the students to explore their data. In summary, the results suggest that the designed educational intervention, which consisted of differentiated online modules within the DME combined with investigation activities using TinkerPlots during classroom sessions, led to increased statistical literacy. However, this study has its limitations: no control with other groups was possible; we cannot indicate whether the differentiated approach or the focus on statistical literacy and reasoning caused the increased level; the pilot took place in just one class, taught by the researcher. Therefore, the results cannot be generalized and further research is needed.

**Acknowledgement**

This study is supported by The Netherlands Organization for Scientific Research (NWO) under project number 636000045.

**References**


