Teaching Spreadsheets to Visually-Impaired Students in an Environment Similar to a Mainstream Class

Dino Capovilla  
Fakultät für Informatik  
Technische Universität München  
Boltzmannstr. 3, 85748 Garching, Germany  
dino.capovilla@tum.de

Peter Hubwieser  
TUM School of Education  
Technische Universität München  
Boltzmannstr. 3, 85748 Garching, Germany  
peter.hubwieser@tum.de

ABSTRACT
Inclusive education at all levels, as required by the UN General Assembly, will increase the heterogeneity of classes noticeably. Computer science education has to change in order to ensure equal access and equal opportunities for all. In contrast to previous research, we developed and tested teaching methods suitable for both normal and visually-impaired/blind students using standard handicap-specific equipment (e.g. laptop and screen reader). Our results show that no additional software and hardware is necessary to reach a fair level of handling spreadsheets when the proposed teaching methods are used.

Categories and Subject Descriptors
K.3.2 [Computer and Information Science Ed.]: Computer Science Education; K.4.2 [Social Issues]: Assistive technologies for persons with disabilities

General Terms
Human Factors

Keywords
Inclusive Education, Spreadsheets, visually-impaired, blind

1. INTRODUCTION
In 2006, the UN General Assembly adopted the Convention on the Rights of Persons with Disabilities. Article 24 states that all States Parties shall ensure an inclusive education system at all levels and lifelong learning [?]. Countries have to dissolve their special schools for disabled people and to include students in mainstream education. This will be a major challenge for Countries like Germany which has maintained a segregational approach up to now.

Assistive Technologies are one of the key factors for educational inclusion and also for an equal participation in society [?]. They are a powerful tool to write and read in a normal way, provide access to information, allow an almost open-minded communication etc. Frequent computer users are more likely to be in employment than rare computer users (47% and 15%, respectively) [?]. But the satisfaction of physical needs is not enough for a successful inclusion. The second key is the possibility to be inconspicuous and hence normal.

Visually-impaired (VI)1 realize their otherness in dealing with normal people daily. This applies in particular for students in an inclusive education system, because they are usually alone among non-disabled people. Their physical difference leads to a strong pressure to adapt. They do not like to be different, and they do not like attention drawn to them [?]. A study by Rodney [?] shows that they are often placed in atypical educational and social situations and therefore they view the support system as a stigmatizing obstacle for the inclusion process. Such atypical situations arise e.g. from striking technical aids, or from the special education teacher sitting next to them.

Additionally, we cannot expect that mainstream teachers are familiar with special aids and didactical concepts for target-group-oriented software. Assistive technologies normally are not included in the curriculum of the degree programs leading to mainstream teacher accreditation. Furthermore, teachers of visually-impaired students (VI) are not prepared to use assistive technology and to teach students how to use it [?, ?]. Besides that, the use of two completely different didactical concepts causes further atypical situations.

Over the last twenty plus years the research in the field of special needs has focused primarily on the development and usability of technology [?]. The results of this research can be seen inter alia from the rising number of visually-impaired graduates in informatics. Furthermore, the survey by Douglas shows that 58% of British visually-impaired persons (VI) of working age use the computer at least once a week, 38% daily [?]. About 41% of British visually-impaired computer users are using spreadsheets regularly [?]. This means, that the necessary technology is available and usable. Now we have to ensure that a maximum number of visually-impaired persons (VI) will be able to benefit from this achievement.

This highlights the crucial role of computer science education. Standard assistive technology for visually-impaired persons (VI) has become almost invisible (e.g. Laptop and Screen Reader). As this first step has been done it is time

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1 In order to increase the readability “visually-impaired” (VI) includes visually-impaired and blind persons/students.
to investigate the necessary changes in teaching methods in order to provide computer science for all.

We started our investigation with spreadsheets, because this type of office software represents a very important tool for computer science classes in our home state [7]. The curriculum of the compulsory subject "Informatics" at our grammar schools is arranged around a sequence of graphical modeling techniques (object and class diagrams, algorithms, data flow diagrams, sequence and state charts) [2]. The curriculum, the teaching approaches, the organizational circumstances and the first outcomes of this newly introduced subject were described very recently in detail in [2]. In order to practice modeling skills, each of those modeling techniques is applied on a specific type of software or programming language, e.g. algorithms on robot systems or data flow diagrams on spreadsheets. Out of this reason, user skills on spreadsheets are an indispensable precondition for the computer science education at our grammar schools.

Tables are an important medium for presenting information as they visualize the data and show particular relations between its contents in a compact way [2]. This practical advantage can be exploited in other subjects. Finally, spreadsheets systems may increase the opportunities for access to employment through the broad application on the labor market.

In this paper, we propose inclusive teaching methods for spreadsheets to reach the technical subject objectives suitable for visually-impaired students (VI) and usable in mainstream classes.

Only a very limited number of people have a visual impairment. Therefore the testing groups in this area naturally are not very big.

2. BACKGROUND AND RELATED WORK

Various researchers described problems which VI have to face while using spreadsheets and that allows us to conclude that most of the other basic tasks can be handled by VI. The following problems were described:

1. Understanding the structure of a table e.g. [3]
2. Knowing what components are in the worksheet - for example tables and charts e.g. [2]
3. Navigating to different components (tables, charts2) e.g. [2]
4. Comparing the content of different cells e.g. [2]
5. Remembering key cell ranges for later use e.g. [2]
6. Handling merged/split cells e.g. [2]
7. Finding specific information e.g. highest/lowest values e.g. [2]
8. Using thresholds to count and identify values e.g. [2]
9. Finding formulas e.g. [2]

In order to solve these problems, three kinds of solutions have been proposed. Doush and Stockman implemented adaptations using VBA [2, 5]. These adaptations are able to detect tables and extract the information to understand the structure. Additional functions allow the user to search for special information like maximum value of a column, to bookmark ranges, find formulas etc.

Kildal proposed a technique to obtain an overview and further information by sonification of the values. The table to be explored is represented on a tablet which can be touched. As low/high numerical values are mapped to low/high frequencies (sounds) e.g. the highest value can be found by locating the highest sound through touching the tablet [1]. Chiousemoglou proposed a haptic device based on Braille to represent the table. The structure of the table can be explored with the fingers [2].

3. METHODS

It is necessary to define a pre-condition for all further considerations: visual impairments differ widely. They range from total blindness, through light-dependent handicaps, to visual field loss. VI should have learned the individual handicap specific techniques (e.g. screen reader, Braille display, display modes) outside the ordinary class in special trainings. This includes safe handling of handicap-specific input and output devices (especially the keyboard), of the graphical user interface, and the basics of file management. This compensates most of the differences between the handicaps and removes the disadvantage compared to normally-sighted students, who are able to tap the basic user skills more intuitively.

What follows is a proposal of an inclusive teaching concept that uses only standard functions of spreadsheets and hence is suitable for all. The concept is based on the following key issues that derive from literature research and about ten years of inclusive teaching experiences in Italy by the authors:

- Teaching should be activity-oriented and integrate experiences from daily life [2, 4].
- Students should create a uniform mental model by using the haptic and visual sensory channels at once [2, 5].
- The teaching concept should be based on the principles and the terminology of object oriented modeling. This offers the advantage of priming in order to reuse this knowledge at a later date [2].
- At least two operation techniques (keyboard and mouse) should be shown. This helps focusing the functionality understanding instead of the user skills training.
- Priority should be given to standard functions.
- We presume that VI are familiar with their individual handicap-specific techniques.
- The different working paces should be considered in lesson planning [2, p. 109].

3.1 Teaching materials

The methods require a set of training materials in order to offer a haptic access. All materials can be bought on the cheap in every toy store or brought from home.

- Toy building bricks and boards (e.g. LEGO™)
- Decks of TOP ASS™ (Top Trumps)™ cards
- Normal Ring file and a few cardboard sheets
- A set of DIN A5 cards (term-cards) labeled with workbook, worksheet, cell, content, Roman numbers, Arabic numbers etc. and featured with ordinary print and Braille. Additionally, we developed three MS Excel™ workbooks:
  - To train the navigation we split the phrases of a few paragraphs of a story4 and wrote them in cells on different

2A standard Screen Reader provides a function to select charts.

3TOP ASS is a card game. Each card contains an item and the attributes with the corresponding numerical data. Players have to try to trump others in order to win the opponent’s cards by comparing the values.

4The Hunger Games written by Suzanne Collins
sheets. The phrases were followed by the cell address of the next part.

- In order to train the elementary functions we prepared a multiple choice test. For example they had to calculate the sum of a column and choose the right answer with the address that leads to the cell containing the next exercise.
- The third workbook contained exercises and examination tasks which we used in mainstream school before.

3.2 Lesson content

To link the abstract notion with the personal experiences of the students, we used the normal ring file as a haptic tool. We pointed out that spreadsheets use the corresponding metaphors. Worksheets can be inserted or cut; it is possible to move to the next/previous worksheet etc.

We made the table concept accessible haptically by the use of toy building boards. The students should understand that the worksheets consist of a fixed number of cells which compose a table. On this toy building boards a cell is represented by a study. By following the studs with the fingers it was possible to explain the relation of rows and columns and hence cell addressing. They had to reflect on the effect of deleting rows and columns and how it is possible that the number of rows and column remains constant.

They had to understand that spreadsheets are a tool to handle relations. In this context the concepts of composition, aggregation and multiplicity were introduced. We dealt the term-cards and the participants had to form pairs and to describe the relations between the terms on their card.

Students had to comprehend tables as a fixed data structure that allows defining several ranges. A range is a subset of the table which must fulfill different criteria. They should develop a formula which sets the number of rows and columns in relation to the number of cells and a method to assign a unique address to a range. Finally, we accentuated the difference (overlapping) between the basic range and the subset ranges.

To solve the problem of finding ranges on worksheets we introduced briefly the idea of loops. Students had to develop a search strategy by using the fingers and the toy building boards and describe their proposals orally.

The use of merged cells leads to a special challenge for VI because maybe the Screen Reader is not able to recognize the correct row/column header. We explained this using the well-known toy building boards and bricks but this time they had to build the border structure and so the cells were represented by the gaps between the bricks. We had to ensure that they understood that the content of the merged cell originates from the upper left cell and that it stays there if cells are split.

Students started to practice navigation and selection in the workbooks mentioned-above. They got a list of the hotkeys and shortcuts (for an excerpt see table 1). We showed one or more ways to solve the problems by using the keyboard. While we explained the mouse technique, VI had to listen carefully. Understanding the use of the mouse helps VI to get a better notion of the software. Sighted participants had to try the keyboard control at least once. Afterwards, they were free to use the mouse. We introduced the bookmark feature to give names to cells and ranges and concluded this part by showing how merged cells could be split individually or for the whole worksheet if necessary.

To introduce the concept of data records from an object oriented point of view we used a deck of TOP ASS (Top Trumps) cards. In order to allow all students to play, the cards featured Braille. As some students of every group had already been familiar with this game, they could already start playing during the breaks. After the break we dealt the cards and they had to create a table and to store the records by using the Attributes as column headers.

For the basic concept of functions we used the black-box view proposed by Hubwieser [7]. In addition to the example of Roman numbers which should support the notion of the existence of non-numerical functions we explained the relation between visual and haptic representation of Braille characters. It could have been that some students did not know the Roman numbers because of their blindness.

Both, VI and sighted participants had to input function names and ranges by typing. This seems to us to be an advantage to understanding the syntax of functions. Of course, during the tests all participants were free to choose the operation technique.

In addition to simple functions (e.g. SUM, COUNT) they had to use the data filter to sort quickly and set thresholds etc.

Table 1: Hotkeys and Shortcuts

| Moves to the next/previous sheet | [ctrl] page down/up |
| Moves to A1 of the current worksheet | [ctrl] home |
| Inserts a new worksheet | [shift] [F11] |
| Moves to the edge of the current data region | [ctrl] arrow keys |
| Select the current region | [ctrl] [F2] |
| Displays the "goto" dialog box | [F5] [ctrl] [F6] |
| Open a Drop-Down list | [alt] [arrow keys] |
| Alternates between cell values and formulas | [ctrl] [C] |
| Format cells dialog | [ctrl] 1 |

The last problem mentioned above is finding formula cells. As they already knew the text structure of formulas we showed them that it is possible to alternate between displaying cell values and displaying formulas by the shortcut. They had to use the find function to search for the equal sign "=". However, it is possible to use the corresponding option of the "goto" function to do this.

3.3 Experiment

Our concept was tested in South Tyrol/Italy in August 2012. The South Tyrolean members of the local Blind Union of working age without mental disorders were invited to participate in one of the two courses on different days. We offered 21 places, seven for each target group: blind, visually impaired and sighted people. A finer pre-selection was not possible because demand was low. The sighted participants were friends of the VI.

Our experiment involved 7 visually impaired, 7 blind and 7 non-disabled participants between 14 and 69 years; 9 of them were female and 12 male with different level of education (9 elementary school, 3 high school and 9 graduated). Their experience using computers differed greatly too (4 daily, 9 sometimes, 8 rarely); 9 of them were employed, 7 students and 5 unemployed/retired.

We had to form two groups of 10/11 participants. This is necessary because VI use earphones simultaneously to understand their own Screen Readers. Therefore, a teacher has

5Center for VI St. Raphael Bolzano
to repeat his instructions at worst as often as VI are in the class hoping that they understand him the first time.

Thirteen (13) of our participants use their own computer environment while the other 8 used computers which were provided by the organizer. A Microsoft Windows™, OSO ran on all machines, a MS Excel spreadsheets system (unfortunately four different versions) on 20 and Open Office on one. The Screen Reader Jaws™ ran on 12 of the 14 computers of the VI; 2 VI did not use a Screen Reader but a Screen Magnification program (1 Magic™, 1 ZoomText™).

Each of the two courses took 7 hours. Two hours were used to teach the theoretical context and to let them experiment with toy building boards and bricks. In the remaining time they practiced and revised what they learned at the computer solving tasks provided by us through workbooks.

Both groups were taught by the visually impaired author himself. He has more than ten years experience in teaching VI and he taught computer science and math at a mainstream school for seven years.

Data arose from different tests during the courses. These tasks were chosen in order to test the handling of the 9 problems mentioned above. We gave the tasks orally and measured the time they needed to fulfill it at the computer. Participants were free to choose an operation technique. If a participant was not able to solve a task we interrupted him. Additionally, we wrote down questions and comments and the results of the exercise (term-cards).

4. RESULTS

Most VI were very skilled in dealing with the toy building boards and bricks. We asked them, what they were thinking while doing this. To reach a specific cell they started from upper left on the toy building board and followed the studs in horizontal direction counting the column labels (A, B, C, etc.). At the correct label they continued following the studs vertically downward till the desired cell. Some of the VI told us, that this technique is similar to reading Braille and that they use the algorithm to find ranges to skim Braille text.

During the path-following exercise we observed that most VI opened a text editor and wrote down the single cell address and the content. This enabled them to return to the previous step while others had to restart. These VI were faster than sighted participants who did not.

Four (4) of the 21 participants were not able to understand and describe our three examples of tables with merged cells. Just 2 of these 4 participants were blind. We noticed during the whole course that these 4 participants had little or no experience with the use of tables. The ability to interpret tables depends first of all on the experience of life.

4.1 Handling spreadsheets

For evaluation we divided the results into three groups: blind (B), visually impaired (V) and sighted (S) persons. The first table 2 shows how many of the 7 participants of each group were able to solve the tasks successfully. The numbers in brackets refer to the corresponding problem mentioned above. The fourth column shows the number of sighted participants who used the keyboard control instead of the mouse (X).

Table 2: Results: Successful solving of the tasks

<table>
<thead>
<tr>
<th>Skill tested</th>
<th>B</th>
<th>V</th>
<th>S</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td>Go to the cell Table2!F323</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>Find the filled range L433:O440</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>Find the range address D43:F49</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Find the only formula (9)</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>Use the SUM on D43:F49</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>Find record on condition =ABV</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Count records on condition &gt;10</td>
<td>6</td>
<td>6</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Compare value (price)/records</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>0</td>
</tr>
</tbody>
</table>

In half of the tests blind participants were faster than VI. VI took longer because some of them tried to use their residual vision first. Doing this they missed the information given acoustically by the Screen Reader. For this reason they had to repeat the operation. 3 of the sighted students tried to find the range L433:O440 by using the scroll bars. This method took much more time. Many participants had problems with the double quote in the COUNTIF formula. This explains the high average values of the task: “count records on condition”. We realized two significant advantages for sighted participants.

Six (6) of the 7 blind, 6 of the 7 visually impaired and 5 of the 7 sighted participant were able to solve all tasks. The performance in the experiment depended first of all on the experience using the computer and the level of education. Significant differences between the target groups could not be observed. Finally, we calculated the arithmetic average of the average times for each group. The average of all tasks from the three groups yielded the following result: 12.6s blind, 13.2s visually impaired and 11.1s sighted.

Table 3: Results: Average time to solve the tasks

<table>
<thead>
<tr>
<th>Skill tested</th>
<th>B</th>
<th>V</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Go to the cell Table2!F323</td>
<td>5</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Find the filled range L433:O440</td>
<td>7</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Find the range address D43:F49</td>
<td>7</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>Find the only formula (9)</td>
<td>5</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Use the SUM on D43:F49</td>
<td>16</td>
<td>23</td>
<td>14</td>
</tr>
<tr>
<td>Find record on condition =ABV</td>
<td>11</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Count records on condition &gt;10</td>
<td>31</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Compare value (price)/records</td>
<td>18</td>
<td>13</td>
<td>12</td>
</tr>
</tbody>
</table>

Average of all tasks          12.6 13.2 11.1

Unfortunately four different versions) on 20 and Open Office on one. The Screen Reader Jaws™ ran on 12 of the 14 computers of the VI; 2 VI did not use a Screen Reader but a Screen Magnification program (1 Magic™, 1 ZoomText™).

Six (6) of the 7 blind, 6 of the 7 visually impaired and 5 of the 7 sighted participant were able to solve all tasks. The performance in the experiment depended first of all on the experience using the computer and the level of education. Significant differences between the target groups could not be observed. Finally, we calculated the arithmetic average of the average times for each group. The average of all tasks from the three groups yielded the following result: 12.6s blind, 13.2s visually impaired and 11.1s sighted.

4.2 Reasons for non-participation

During the invitation to the courses we noted very interesting behavior. We offered two identical free courses on different days. With the help of the Center for VI St. Raphael Bolzano we invited 76 people to participate. 27 of the VI contacted were between 12 and 19 years and attended mainstream school (in Italy does not exist segregation). Just one of them participated in the courses. As we found this very interesting we decided to contact them (children or parents) again to ask for the reasons.

Five (5) convinced us credibly that they had no time to participate. 9 said that they are not interested in the sub-
ject. 3 told us that they would attend a normal course if necessary. 2 declared explicitly that they were not interested in contacts with other handicapped people and the remaining 8 could not be contacted again.

5. DISCUSSION

The considerable ability to handle cell navigation with the toy building board of VI could be interesting for teaching to program. Karel the Robot’s world is based on a 2D grid. Karel can be moved horizontally and vertically and be turned on the intersections \(\square\). Toy building boards and bricks seem to be suitable to make Karel’s world haptically accessible.

Some VI developed a method to represent recursive linear lists while doing the path finding exercise. They wrote down the address of the next cell (vertex) and the current content in a text file. This seems to be reusable for teaching graph theory. It would be interesting to investigate how these VI students would represent trees.

Stockman argues the necessity of software adaptations inter alia with an insufficient knowledge of keyboard-based spreadsheet navigation techniques of VI [?]. We propose to teach these elementary techniques and the test has shown that this is possible. As we explained, this allows VI to be taught in mainstream classes because they do not need a different teaching concept that would be contrary to inclusive education.

The development of algorithms to analyze tables is interesting to improve spreadsheets in general and some ideas may enhance the quality of standard Screen Reader systems. However, it does not make sense to substitute or overwrite the standard function of the spreadsheet software as happened e.g. in the proposal of [?] for the maximum/minimum search.

This restricts the VI to the range of functions offered by the developer, in the absence of deeper understanding of the spreadsheet concepts. If the teaching of basic concepts as we have shown will not be possible it is doubtful that spreadsheets will be used in a sensible way by the VI.

Most of the tables used in education and professional life can be handled by using the standard functions by VI. Surely it will be possible to find or create tables that let VI push their limits. In such cases additional hardware like the Braille device proposed by Chiousenoglou [?] may be helpful. But if we weigh the cost against the benefit it would be better to accept some limitations.

Furthermore, we should remember that sighted people resolved the problem of handling unmanageable data sets by developing database technology. As SQL can be used text-based this is a sustainable way for a VI too.

5.1 Limitations

Small sample size was the major limitation of the experiment. Fortunately the number of VI is relatively small. Therefore, the preconditions (educational and social backgrounds, disabilities etc.) are very different in larger groups. We considered the opportunity to test the concept in inclusive mainstream classes but the presence of a foreign teacher would have lead to further atypical situations for the included VI and we decided to try to reduce such situations.

6. CONCLUSIONS

We proposed several inclusive teaching methods suitable for VI. It introduces the idea of spreadsheets and allows the solving of the problems mentioned-above through using only the standard functions. This means that from the technical point of view subject objective of spreadsheets can be reached by VI in mainstream classes.

Future work will include the adaption of the following topic comprised by the curriculum in order to give further suggestions to teachers who share our conviction that education should be accessible for all.