Some Evidence for the Impact of Limited Education on Hierarchical User Interface Navigation

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ABSTRACT

One of the greatest challenges in designing applications for economically poor communities is that potential users may have little or no education. We investigated how limited education appears to impact the ability to navigate a hierarchical UI, even when it has no text. We scored 60 participants from low-income communities in India using tests of textual literacy and Raven's Progressive Matrices. These were used as proxies for educational level and a subset of cognitive abilities. We then evaluated participants' performance on a UI task involving hierarchical navigation. First, our results confirm that textual literacy is correlated with scores on the Raven's test. In addition, we found that performance on both instruments are predictive of performance in navigating UI hierarchies, even when the UI is text-free. This provides statistically significant confirmation of previous anecdotal hypotheses. We conclude with design recommendations for UI hierarchies for people with limited education.

Author Keywords

Limited education; abstract reasoning; hierarchy navigation

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

General Terms

Human Factors; Design; Measurement.

INTRODUCTION

One of the greatest challenges faced in designing computing applications for economically poor populations in the developing world is that potential users may have little or no education, which often means illiteracy and underdeveloped cognitive skills.

Most of the existing work in this area focuses explicitly on users' inability to read, with little recognition given to other cognitive challenges. On the one hand, this is understandable. More than 800 million people in the world are completely non-literate [56], and many more are able to read only with great difficulty. Therefore, non-textual UIs that use voice, graphics, and video have been proposed. [10, 21, 23, 37, 38, 54].

On the other hand, related work suggests that the inability to read is only one of many challenges faced by people with limited education [35, 36].

Cognitive science studies in *developed* countries have long confirmed this observation, showing definitively that people with limited education differ from people with good educations in their performance of a variety of cognitive skills. One study found that illiterate Dutch-language speakers performed relatively poorly across the board on a battery of cognitive-skills tests, compared with their literate counterparts [57]. Meanwhile, one recent conception of "digital literacy" proposes that it requires a whole family of "literacies," involving photo-visual, reproduction, branching, information, and socio-emotional capabilities, most of which have little to do with textual literacy [15].

Our own informal observations from previous studies suggest that people with low literacy have difficulty with computer UIs even when they are absent of text. We speculate that among other things, the hierarchical information architectures (IAs) that traditional computing software depend upon – menus, folders, and so on – pose challenges for people whose cognitive skills may be underdeveloped due to low levels of education.

In this study, we show that limited education impacts the ability to navigate a hierarchical UI, even when it has no text. While previous work has shown this anecdotally for a variety of low-education communities, we provide the first empirical demonstration of this hypothesis to our knowledge. We conducted a controlled experiment with 60 participants from low-income communities in India and classified them based on tests of their textual literacy, used as a proxy for overall educational level, and non-verbal abstract reasoning, as measured by Raven's Progressive Matrices [49]. We then evaluated their performance on a UI task involving hierarchical navigation. We confirmed first that textual literacy is correlated with scores on the Raven's test, at least for these participants from three urban South Indian slum communities. In addition, we found that both textual literacy and non-verbal abstract reasoning (as measured) are predictive of performance in navigating UI hierarchies, even when the UIs are text-free.

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To be clear, we do not claim that textual literacy or the abilities measured by Raven's test *per se* are responsible for navigating hierarchies. Nor have we proven that formal education itself is required for literacy or non-verbal abstract reasoning. Rather, we believe that education results in the training of a variety of cognitive abilities, some of which are related to hierarchical navigation. We conclude with design recommendations for UI hierarchies for people with very limited education.

RELATED WORK

UIs for Non-Literate Users

Previous work in UIs for users with little or no education has mostly focused exclusively on the inability to read, by adapting interfaces on PCs, PDAs, and mobile phones that usually use text. To help work around non-literacy, researchers have recognized the value of imagery and graphics [21, 23, 38, 46] as well as audio feedback [38, 46, 47]. Speech interfaces are also popular [7, 47, 54]. And of course, video is routinely cited as a means to communicate with non-literate users [17, 29, 34].

The work mentioned above focuses on avoiding the use of text, but some work also addresses concerns other than strictly textual non-literacy. One paper focuses on ultra-simple navigation as a design goal [21], for example. Others have questioned menu-based navigation for novice users [24, 25] and have discussed designs that advocate fewer menus and dedicated buttons for this target group [28]. The evidence in these studies, however, is anecdotal, and it's not clear whether the design recommendations are meant for *novice* users or users who may have ongoing challenges with complex UIs.

One study that brings this issue to the forefront speculates that when compared to educated users, users with limited education have "less developed cognitive structures and linguistic sequential memory." The study calls for attention to these speculative structures when doing instructional design for rural e-learning applications [26]. The work we present in this paper is intended to investigate this possibility more deeply and to reach credible design recommendations.

Limited Education and Cognitive Science

Studies in the cognitive sciences conducted in the developed world provide strong evidence that formal education enhances general cognitive skill development.

Most of these studies use either years of schooling or tests of reading and writing as proxies for education level. Assuming that the use of such proxies is justified, the studies go on to show that educational level correlates with various cognitive and non-cognitive traits — visuospatial and visual organization [4, 33, 51]; linguistic ability [1, 9, 28, 40, 50]; and self-efficacy [5, 12]. As to the mechanism, researchers suggest that in addition to the skills of reading and writing, educated people acquire skills and strategies to organize and process information in less idiosyncratic and more efficient ways compared with people who have little or no education [31, 32, 57].

Of partial relevance to graphical UIs, participants with limited education have been shown to have difficulty recognizing abstract icons, with specific challenges integrating 2D line drawings into meaningful wholes [9]. In yet another study, participants with limited education performed significantly worse on rapid naming of two-dimensional representations of common, everyday objects compared to well-educated participants, both in terms of accuracy and reaction times [51].

Most of the work discussed above was conducted in developed regions—North America and Western Europe—and therefore, is subject to caveats of cultural specificity. Nevertheless, this work strongly confirms the evidence that formal education enhances certain cognitive skills, certainly beyond the mere ability to read and write. If anything, in environments where standards of education are even poorer, we might expect differences in cognitive skill arising from educational quality to be even more pronounced.

Finally, there has been some work in Nigeria and the Philippines to understand the impact of limited education on cognitive processes such as deductive reasoning and conceptual categorization [3, 6]. In our work, we investigate how limited education impacts the ability to navigate a hierarchical UI, relevant in the context of meaningful interaction with information technologies.

Anecdotal Evidence

In an analysis of hierarchical classification skills related to science education in the developed world [30], top-down hierarchies were said to consist of broad inclusive concepts at the top levels that subsume less inclusive concepts at the lower levels. It was then proposed that abstract reasoning is necessary to discriminate specific attributes of the low-level categories, and these attributes can be combined to form generalized representations of the high-level categories. If this study is right about non-verbal abstract reasoning being important to understanding hierarchical classification, then abstract reasoning is likely to be one of the critical skills for manipulation of interactive architectures as well. The conclusion, however, remains speculative.

The most relevant research for our study comes from anecdotal evidence in the field of information technology for international development. This work suggests that a host of issues inhibit users with limited education on computing applications: lack of awareness of what computers can deliver; intimidation caused by technology; pricing of a service; social standing; non-verbal cognitive capacity; and others [35].

One empirical study investigated how video-based learning transfers to actual practice [36]. It found that test participants with limited education performed relatively poorly compared with participants with some basic education.

In our own experience with low-literate users in India, the Philippines, and South Africa, we have encountered anecdotal evidence that limited education is correlated with difficulty using computer UIs even when they are absent of text. We saw frequently that users with limited education seemed more comfortable with linear navigation structures than branched, hierarchical structures. Similar anecdotal evidence by other researchers in South Africa also gestures towards similar conclusions [25].

The study in this paper seeks to confirm and refine these anecdotal reports with a more rigorous study.

AN ETHICAL NOTE

We recognize that portions of our hypothesis will be controversial to some readers. The claim that less educated people have less of some cognitive skill can be misinterpreted as either a form of discrimination or a kind of "blaming the victim." Our intentions, however, are ultimately to support people from less advantaged backgrounds, but doing so requires a realistic view, not a pollyannish clinging to a romantic, non-existent equality. This section provides a reasoned defense of our stance, which we hope will not be misrepresented or politicized.

First, we refer to, and agree with, the extensive cognitive science literature (only sampled in the previous section) that limited education stunts cognitive development. Indeed, to deny that there could be differences in cognitive ability due to education is to deny the deeper value of formal education. One of the key roles of a good education is to enhance cognitive skills, so unless education itself has failed in this mission, it should not be surprising that people with different levels of education have different levels of cognitive skill.

Second, we understand alternative interpretations, such as that people with different degrees of formal education are merely differently abled. Two studies insist that hierarchical tree structures for classification are a culture-specific visual form that excludes non-Western people on graphical, architectural and ideological levels [27, 58]. It might very well be that those without formal educations have other advantages that our study does not explore – we do not deny that. However, in the context of computing technology use, it is nevertheless the case that the different abilities we focus on appear to correlate with less user capability.

Finally, we outright deny any interpretation of our work that implies a fundamental deficiency in the *potential* of any given group, including any group that includes our participants. At most, we are suggesting that *actual* abilities suffer from a lack of good education or the equivalent. If anything, our hope is that a superior understanding of user capabilities leads to renewed effort to fill educational gaps and to designs that are more equally usable by all.

THE STUDY

Our intention is to understand how limited education might lead to differences in the ability to navigate hierarchical user interfaces. Prior to the experiment and based on anecdotal evidence, we speculated that limited education leads to stunting of certain cognitive skills which are important for hierarchical navigation.

We cannot prove this causal hypothesis conclusively without running an experimental trial in which some randomly selected participants (the experimental group) are given a formal education while others (the control group) are denied one. Without such an experiment, it's possible that a latent third variable that influences whether someone receives a good education also separately influences their ability to navigate hierarchies. But for ethical and logistical reasons, such an experiment is difficult.

Instead, this study seeks to provide correlational evidence that links formal education with certain cognitive abilities and with the ability to navigate hierarchical UIs. To do this, we need to do three things: First, we establish participant educational level among a group of participants in which the level varies. Second, we determine their ability for non-verbal abstract reasoning. Third, we measure their ability to navigate hierarchies.

The research questions we are asking are…

- Is education level correlated with ability for some kind of abstract reasoning?

- Are education levels and ability for abstract reasoning predictive of performance in navigating UI hierarchies?

METHODOLOGY

Testing for educational level

Some studies in UI design and cognitive science use years of formal schooling as a proxy for education level. However, reported quantity of education rarely coincides with quality of education, especially in the developing world, where many students reporting to have attended school for years cannot read or write at all.

Thus, following some of the cognitive science literature [32, 50, 57], we use textual literacy—the ability to read and write at the time of the study—as a proxy for the overall quality of education of our participants. In a sense, we are after the net result of the education that participants have received (in whatever good or bad a form), and the ability to read and write is a good indicator of it, at least for the participants and the context that we are interested in.

A review of existing assessment tools for literacy (Western [2, 11, 16, 41, 42, 55] and Indian [43, 44]) did not reveal a suitable instrument to measure literacy for our participants. Most such instruments discriminate among a much higher level of literacy or do not discriminate sufficiently between levels of literacy. Western tests tend to assume basic literacy, while Indian tests, for example, result only in a binary "literate" or "illiterate" result. Thus, we devised our own textual literacy scale, following the established practice of that literature but using content from standard local language government school textbooks.

In consultation with a researcher specializing in primary education, we derived questions from textbooks for grades I, III, V, and VII in Kannada, the native language of our participants [18]. Level 0 corresponded to no ability to read; level 1 corresponded to the ability to read and write grade I content; level 2 to grade III; level 3 to grade V; and level 4 to grade VII. Our target community does not contain test participants with formal education beyond grade VII; hence level 4 (grade VII) was taken as the highest level. The test questions were picked so that there was a meaningful distance between successive levels, which is why content from grades II, IV, and VI was excluded.

Every level had two sections: reading and writing. A numerical scoring system was devised for the purpose of grading participants. The total marks allotted for each level was 50 (25 for reading and 25 for writing). Expectations of the textual literacy scale are summarized in Table 1.

Table 1. Textual literacy assessment scale

	Reading (total score: 25)	Writing (total score: 25)
Level 0 (Non-Literacy)	Not applicable (Score 0)	Not applicable (Score 0)
Level 1 (Grade I) +0	Letters, Words, Sentences	Letters, Words
Level 2 (Grade III) +50	Passage I, II; Reading comprehension	Sentences, Paragraph
Level 3 (Grade V) +100	Reading Comprehension I, II	Paragraph I, II
Level 4 (Grade VII)+150	Reading Comprehension I, II	Short essay I, II

Process of administering and scoring the test

Test participants were first administered the test corresponding to their reported years of formal schooling, e.g. Level 3 (grade V content) for a participant with grade V or grade VI formal education. Depending on their performance on a test, some participants received follow-up tests. If the participant made no progress on the initial items of a test in spite of probing from the experimenter, that test level was discontinued and the test from the level just below it was administered (e.g. in this case Level 2 (grade III content). If the participant easily passed a level, the test above it in level was to be administered (though this event did not happen in practice). There was no time limit to complete the test, though in practice, no participants took longer than 40 minutes.

Literacy scores were then computed as follows: For each participant, the highest test for which a participant was able to complete some but not all of the test was chosen. Fifty points were then added for each test level below the corresponding test. (Thus, someone who partially completed a Level 2 test was given a starting score of 50.) Then, the score on the test (between 0-50) was added. Final scores ranged from 0 to 200, with no overlap of scores among levels.

Testing for abstract reasoning

To show that level of education correlated with cognitive skill, we needed a measure of non-verbal abstract reasoning. Our search yielded a number of tests that we eventually rejected: the California Proverb's Test [19], the Mednick's Remote Associates test [39], Draw a Person Test [20] and Duncker's Candle Test [13]. These tests had a variety of problems: some assumed literacy; others were not standardized; and still others were culturally specific.

UItimately, we settled on Raven's Progressive Matrices [48, 49]. This test is composed of non-verbal multiple choice questions: in each test item, the participant must identify the missing element that completed a sequential visual pattern (see Figure 1). Raven's matrices do not require literacy, are well validated in the psychology literature, and are among the most cited tests for measuring abstract reasoning [8, 22, 52]. In the adapted version of the standard test we use, 18 patterns are presented in the form of a 3x3 matrix [14].

Process of administering the Raven's test

Test participants were first shown 3 Raven's matrices questions, each of whose solution was demonstrated by the experimenter. Then, they were given 20 minutes to solve 15 additional Raven's matrices questions on their own. A point was awarded for each question solved correctly.

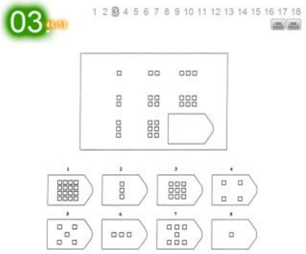

Figure 1. Item 3 of Egopont's Raven's test

UI prototypes

For the UI prototypes, we looked for a domain that met the following criteria: a) allowed for test items to be represented graphically with no text; b) was widely understood by our participants; c) was gender neutral; and d) would allow for extensive categorization. In consultation with members of the target community, we considered various domains such as health disorders, agricultural tools, and railway reservations, but ultimately settled on household items such as items of clothing, jewelry, utensils, electronics, games and sports, etc. A total of 40 household items were selected for the prototype design.

Figure 2. Participant categorizing printed cards

To ensure that any cultural biases affecting hierarchies were consistent with those of our participants, we conducted a validation of categories with 8 people who were members of the target community but not members of the eventual study (4 male, 4 female). Forty printed cards, each containing one household item, were presented to each participant (see Figure 2). The task was to group the items into categories recursively until they reached a point where all items were in one set. Three people completed the exercise all the way to the top of the hierarchy; the remaining five were able to create some meaningful clusters, but did not complete the full hierarchy, i.e. were unable to collapse clusters further. Item groupings were largely consistent within the participants and also with our own "common sense" groupings, and they formed a basis from which we were able to design the navigational test.

We constructed three organizations in increasing order of hierarchical depth:

- A flat UI of 40 items, organized in a grid and all at the same level, displayed all at once on the screen.
- A shallow hierarchy UI of 40 items (2 levels deep with average branching factor of 8). The items were organized in a top-down navigation tree based on two levels of organization: first level is the *item category* (e.g. Clothes, electronics, jewelry, etc.), and second level is the *type of item* (Shirt, TV set, bangles, etc.). See Figure 3, bottom, for the structure but not the actual display.
- A deep hierarchy UI of 40 items (4 levels deep and average branching factor of 3). The items were organized in a top-down navigation tree based on four levels of organization: first level is *how the item is used* (e.g. things you wear, things you use), second level is *item category* (e.g. Clothes, electronics, jewelry, etc.), third level is *item sub-category* (Men's clothes, living room electronics, hands jewelry, etc.) and *fourth level is type of item* (Shirt, TV set, bangles, etc.). See Figure 3, top.

All interfaces were completely graphical with no text. Each of these UI prototypes were displayed on a Tablet PC Lenovo X200. Clicking with the stylus on a certain graphic would take the user to the next level of the hierarchy until a leaf item was reached. At every level, there was a provision to return to the previous level in the hierarchy by clicking on a "back" button at the bottom right corner (Figure 4).

Process of administering the UI test

Each participant was randomly allotted one of the prototypes (list / shallow hierarchy / deep hierarchy). Participants were asked to carry out five tasks: each task required them to find a given household item on the UI that was allotted, such as set of bangles, water pot, a football, a pair of shorts and a mixer-grinder. There was a time limit of 2 minutes for every task. We used the timing in the UI test solely as a mechanism for making progress with participants; the fact that participants were timed was not announced to them to avoid causing anxieties of time pressure (often reported in previous studies with similar groups) – what they experienced was that occasionally, we would simply prompt them to go ahead with another task.

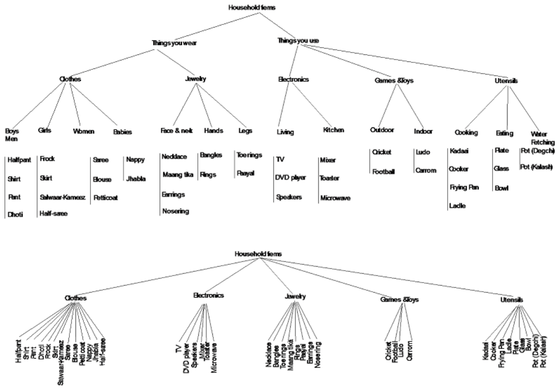

Figure 3. Deep UI architecture, (above): shallow UI

Figure 4. Screenshot of a page from the deep hierarchy UI

A standardized set of verbal instructions was provided at the beginning of the test by the experimenter. A two-minute instructional video on how to use the UI on the Tablet PC was shown. The video had details on how to hold the stylus; how to hover and click; and explained the concept of nesting. Participants could watch the video up to three times if they wished. The domain for the instructional video was animals-birds kingdom instead of household item, so there was no learning effect on the content itself. There was no additional assistance provided by the experimenter thereafter.

The UI test was scored based on the number of correct selections (maximum 5), as well as by the time taken to complete the task.

Table 2. 3X3 experimental design with nos. of participants (m=male, f=female)

	Low literacy (Level 0-1)	Medium literacy (Level 2-3)	High Literacy (Level 4)
Deep	7 Nos. (4m, 3 f) mean age: 38 yrs	7 Nos. (4 m, 3 f) mean age: 34 yrs	7 Nos.(4m, 3f) mean age:30 yrs
Shallow	7 Nos. (4 m, 3 f) mean age: 38 yrs	7 Nos. (3 m, 4 f) mean age: 34 yrs	7 Nos. (4m, 3f) mean age:31 yrs
List	6 Nos. (3 m, 3 f) mean age: 39 yrs	6 Nos. (3 m, 3 f) mean age: 40 yrs	6 Nos. (3m, 3f) mean age:34 yrs

Participants

Test participants were drawn from three urban slum communities in Bangalore, India. They were recruited through an intermediary organization doing developmental activities in the slum areas. Most people that were recruited were in informal sector jobs: drivers, security personnel, vegetable vendors, domestic workers, motor mechanics, etc. Younger participants were secondary school students from the same slum communities. The household income of participants was less than about INR 6500 (USD 120) per month. The age range was 18-65 years. Their primary language of communication was Kannada. Apart from this, a few people also spoke Tamil, Hindi, and smatterings of English. None of the participants had any previous experience using computers. Most male participants owned and used personal mobile phones. Younger participants used mobile phones for texting, but among older mobile phone users, usage was limited to voice calls only. Most people did not use their phone books and to make calls and dialed numbers from scratch every time. In terms of other technology use, TVs, DVD players, CD players, and electric blenders were common items in participant households.

Experimental procedure

60 participants were recruited for the study. Attempts were made to involve a diverse group across age and gender.

For consistency, the same researcher acted as experimenter for all participants and followed a fixed script. Participants came in one by one. The researcher first gathered information about the participant such as their age, years of formal schooling, and technology usage. Then, each participant took each of the literacy test, the Raven's test, and one version of the UI test.

We conducted a 3x3 between-subjects experiment design. There were 3 kinds of UI prototypes – list, shallow hierarchy, and deep hierarchy. The 5 levels of literacy were collapsed into 3 – low (level 0-1), medium (level 2-3), and high (level 4) to create roughly equal-sized groups out of our participant pool. Thus, there were a total of 9 experimental conditions. Each condition for the deep and shallow hierarchies had 7 test participants, and list had 6 participants each.

The experimental design is illustrated in Table 2, together with mean ages and gender break-up. The mean age of the high literacy groups was lower than those of the medium and low literacy levels for all UI categories; the more literate participants in our target communities tended to be younger. This is likely due to the increase in school enrollment and quality of education in recent years, owing to the Government of India's efforts towards universal elementary education [53].

Documentation

We collected notes in situ on paper and timed the UI tests and Raven's tests. To avoid participant anxiety, we did not video record the user tests. Select photographs of the test participants and testing environment were also taken. There was one experimenter and one additional research assistant for note-taking.

Hypotheses

Finally, we expected to observe the following correlations:

1) Literacy scores correlate with Raven's test for non-verbal abstract reasoning.
2) Performance on navigating hierarchies correlate with literacy score.
3) Performance on navigating hierarchies also correlates with Raven's test for non-verbal abstract reasoning.

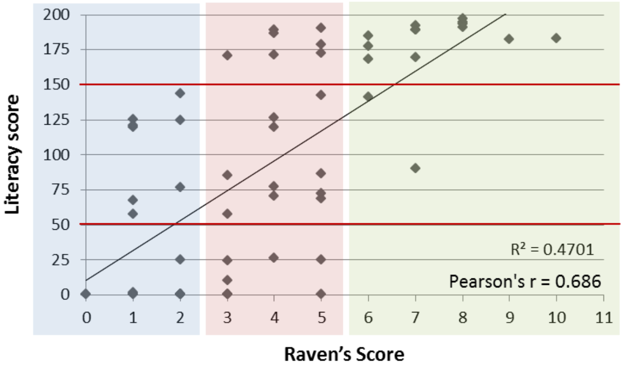

Figure 5. Scatterplot for Raven's score vs. literacy score

RESULTS

Quantitative results

Experimental results confirmed all three hypotheses.

Confirming our first hypothesis, higher literacy test scores were correlated with greater non-verbal abstract reasoning. A Pearson product-moment correlation coefficient was computed to assess the relationship between the literacy test scores and Raven's scores across all participants. As seen in the scatterplot in Figure 5, there was a positive correlation between the two variables with $r = 0.68$, $p < 0.01$ ($n = 60$).

Figure 6 shows how navigation ability correlates with literacy scores. Confirming our second hypothesis, greater

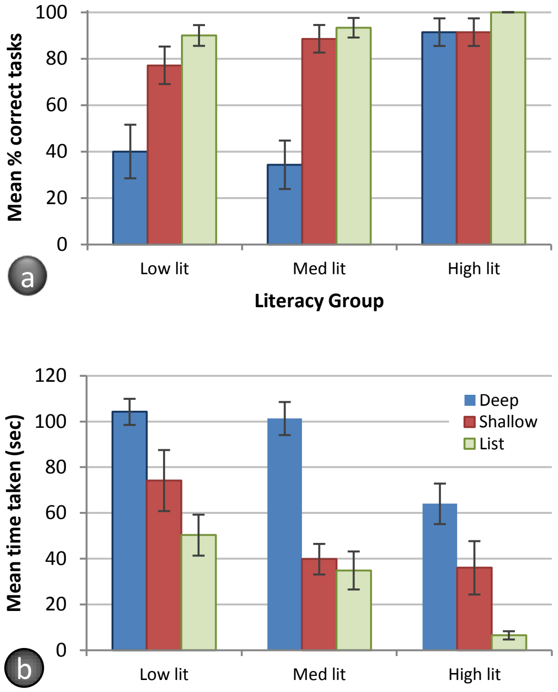

Figure 6. (a) Mean % correct tasks and (b) mean time taken across all UIs, by all literacy groups (±SEM).

literacy correlated with greater task accuracy. In Figure 6a, participants with high literacy completed more tasks correctly on the deep hierarchy, than groups of participants with low literacy (average of 91 vs. 40), $t(12)=3.96$, $p<0.01$, as well as those with medium literacy (average of 91 vs. 34) $t(12)=4.76$, $p<0.01$.

Also confirming the second hypothesis, participants with high literacy required significantly less time to navigate each UI. Figure 6b shows, for example, that participants with high literacy took less time to complete the deep hierarchy tests than participants with low literacy (average of 64 vs. 104 seconds) $t(12)=3.81$, $p<0.01$, as well as those with medium literacy (average of 64 vs. 101 seconds), $t(12)=3.26$, $p<0.01$.

Figure 7 shows UI navigation performance as related to their non-verbal abstract reasoning ability. Three groups of abstract reasoning were created based on Raven's scores:

- Low (Raven's score 0-2), 20 participants
- Medium (Raven's score 3-5), 25 participants
- High (Raven's score 6-15), 15 participants

Confirming our third hypothesis, greater ability for non-verbal abstract reasoning correlated with greater navigational accuracy. So, for example, participants with high abstract reasoning completed more correct tasks on the deep hierarchy, than groups of participants with either low abstract reasoning (average of 92 vs. 42), $t(12)=3.79$, $p<0.01$, as well as those with medium abstract reasoning (average of 92 vs. 45), $t(12)=3.09$, $p<0.01$.

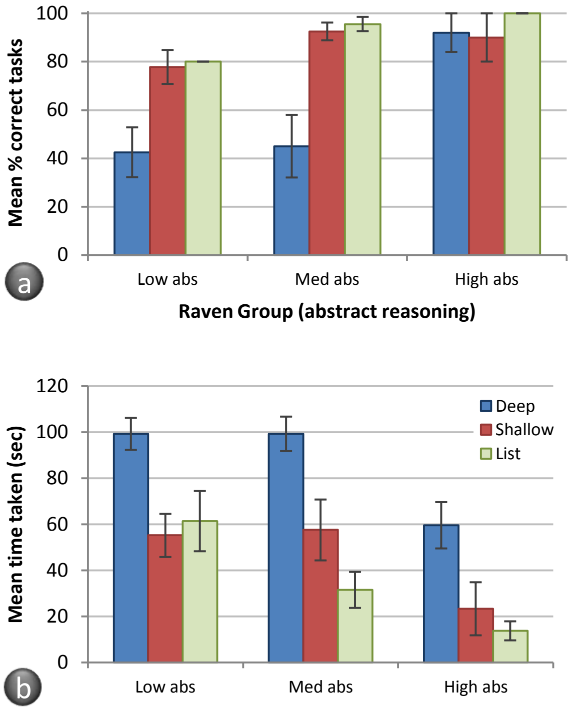

Figure 7. (a) Mean % correct tasks and (b) mean time taken across all UIs by all abstract reasoning groups (±SEM).

Also, participants with greater abstract reasoning ability tended to require less time to navigate each hierarchy. For example, high abstract reasoning required less time to navigate the deep hierarchy, than participants with low abstract reasoning (average of 59 vs. 99 seconds), $t(12)=3.25$, $p<0.01$, as well as those with medium abstract reasoning (average of 59 vs. 99 seconds), $t(12)=3.17$, $p<0.01$.

Qualitative results

We had a number of qualitative observations during the UI tests and follow-up informal conversations with the participants, which could inform future studies. There may be a number of possible explanations for these observations, and we leave it to future work to explore them.

First, among the participants who could not complete tasks correctly or who took more time to complete them, many used an approach of random selection. So, to find a water pot on the item categories page, one participant serially tapped graphics representing "electronics", "jewellery" and "games and sports," before finally selecting the one for "utensils." They did not seem to understand the concept of nesting, that the top graphic in a hierarchy represented a group of pages, or that selecting items corresponded to "progress" within the hierarchy. This was in spite of video instructions explaining how some items were "contained within" other item categories and showing how selecting a graphic would take the participant to the items contained within that category.

Second, some people did not remember how to navigate back to higher levels once they had gone down the incorrect path in the hierarchy. Further conversation revealed that they had forgotten the "back" button from the instructional video. We suspect this could be because of deficiencies in short-term memory, inattention during the video instructions, or inexperience in following such instructions.

Finally, our follow-up conversations revealed that some participants did not understand that they had to apply what they had learnt in the instructional video to actual usage during the UI tests. One participant remarked, "But that was about animals and birds, and this is about clothes and TV sets." This observation seems consistent with findings from other research describing the effect of limited education on transferring relevant learning from an instructional video to actual practice [36].

ANALYSIS

Our study rigorously confirms for the first time that in at least one set of low-income communities in South India, less literate users have lower levels of non-verbal abstract reasoning as measured by Raven's matrices, and that those with less literacy and less skill at non-verbal abstract reasoning also have greater trouble navigating hierarchical UIs, even when the UIs are entirely devoid of text. The effect is more pronounced when the UIs involve deeper hierarchies. Our study also shows that the correlations are transitive, and that there is a strong direct correlation between literacy and performance in navigating hierarchical UIs.

This study taken in isolation does not allow us to deduce causal relationships between these traits, nor have we isolated the exact cognitive abilities that facilitate navigation of hierarchical UIs. Those remain open questions for future work.

However, our results taken in conjunction with other work provide support for somewhat broader claims. These claims undoubtedly require confirmation from further research, but we believe they are considerably more than blind speculation.

First, it seems reasonable to take degree of literacy as a proxy for quality of education, at least in modern societies where early formal education stresses textual literacy, and up to some level of education where there are differential levels of literacy. This correlation is partially tautological – a good modern education could be defined as that which confers high literacy, whether or not it is delivered in a formal classroom.

Second and if so, our study supports other studies [3, 31, 32, 33, 51, 57] that show that education helps to develop a certain class of non-verbal abstract reasoning abilities. It may be that formal classroom education is not required to develop these skills – perhaps some unorthodox teaching methodology would do just as well – but in any case, formal education is a mechanism for nurturing abstract reasoning capacity.

Third, because it seems unlikely that literacy itself – the ability to understand and produce text – is directly responsible for the ability to navigate non-textual graphical menus, we infer that it is some set of non-verbal cognitive skills that facilitates the navigation of hierarchical UIs.

Fourth, by putting the above reasoning together, we can surmise that formal education leads to the development of some set of non-cognitive skills that happens to support hierarchical UI navigation.

Finally, given that similar evidence, though anecdotal, has appeared in geographically diverse research in India [36], the Philippines [37], South Africa [24], it seems reasonable (though by no means certain) that this conclusion applies to low-income populations with limited education more generally. Exceptions might occur in oral societies that nevertheless stress the development of non-verbal cognitive abilities.

RECOMMENDATIONS

The broader conclusions lead to several recommendations. First, they lend further support for good formal education in international development, because it provides a basis for interacting with the information technologies that increasingly permeate modern global society. We note that to this end, even a basic education that involves no explicit *computer* literacy is essential – our studies show a correlation between textual literacy and cognitive skill and performance on computer UI navigation *even among participants that had no prior experience with computers*.

Second, when designing for populations with limited education, our conclusions support earlier recommendations towards simplified UIs [37, 38]. In particular, we recommend keeping navigational UIs linear to the extent possible and to minimize hierarchical depth even at the expense of conciseness. Alternatively, it is worth exploring designs that provide some of the advantages of hierarchies without losing the simplicity of flat lists. For example, listed items could nevertheless be grouped according to categories with markers indicating category boundaries to aid search for those who do grasp hierarchies.

Third, despite our conclusions, we oppose cognitive testing for design whereby something like IQ tests are administered to users as a way to decide the UIs appropriate for them (in a manner analogous to "personality-targeted design" [45]). From a practical perspective, the correlations we discovered are far from perfect – there are plenty of intervening factors that we do not fully understand. From an ethical standpoint, it seems a slippery slope to various forms of discrimination, intended or otherwise.

Finally, the overarching recommendation is that UI designers should not assume that the inability to read is the only obstacle to UI facility among non-literate users.

CONCLUSIONS AND FUTURE WORK

In this study, we demonstrated rigorously that in at least one set of communities in South India, levels of literacy correlate with ability for non-verbal abstract reasoning (as measured by Raven's matrices) and that both correlate with the ability to navigate a hierarchical UI even when the UI contains no text. To the best of our knowledge, this is the first empirical demonstration of this previously anecdotally supported hypothesis.

Combining this conclusion with other work, we further infer less conclusively that limited education stunts certain cognitive abilities that are important for navigating hierarchical UIs. Also, while our participants were chosen from a particular community in South India, given the anecdotal evidence from previous work in the Philippines and South Africa, we anticipate that similar conclusions will map to other low-education communities as well.

Future work could ask the following questions. What specific cognitive skills make up the ability to navigate certain UIs? Can the use of digital interfaces themselves increase some cognitive capacities? How might limited education impact speech and touch interfaces, which are generally understood to make systems accessible to low-literate users? These are all related areas for further investigation.

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REFERENCES

1. Abadzi, H. (2003). Improving adult literacy outcomes: Lessons from cognitive research for developing countries. Washington, DC: World Bank.
2. Adult Literacy Supplemental Assessment (ALSA). (n.d.). Retrieved from http://nces.ed.gov/naal/alsa.asp
3. Akinnaso, N. (1981). The consequences of literacy in pragmatic and theoretical perspectives. Anthropology & Education Quarterly, 12(3), 163-200.
4. Ardila, A., Rosselli, M., & Rosas, P. (1989).Neuropsychological assessment in non-literates: Visuospatial and memory abilities. Brain Cognition, 11(2), 147–166.
5. Bandura, A. (2005). Self-efficacy. In V. S. Ramachaudran (Ed.), Encyclopedia of human behavior (pp. 71–81). New York: Academic Press
6. Bernardo, A. (2000). Literacy and the mind: The contexts and cognitive consequence of literacy practice. Luzac Oriental.
7. Boyera, S. (2007). The mobile web to bridge the digital divide? Paper presented at the IST-Africa Conference 2007, Maputo, Mozambique.
8. Brouwers, S. A., Van de Vijver, F. J. R., & Van Hemert, D. A. (2009). Variation in Raven's Progressive Matrices scores across time and place. *Learning and Individual Differences, 19,* 330-338.
9. Castro-Caldas, A. (2004). Targeting regions of interest for the study of the non-literate brain. International Journal of Psychology, 39, 5–17.
10. Chipchase, J. (2005). Understanding non-literacy as a barrier to mobile phone communication. Retrieved from http://research.nokia.com/bluesky/non-literacy-001-2005/index.html
11. Comprehensive Adult Student Assessment Systems (CASAS). (n.d.). Retrieved from https://www.casas.org/home/index.cfm?fuseaction_home.showContent&MapID_198
12. Czaja, S. J., Charness, N., Fisk, A. D., Hertzog, C., Nair, S. N., & Rogers, W. A. (2006). Factors predicting the use of technology: Findings from the Center for Research and Education on Aging and Technology Enhancement (CREATE). Psychology and Aging, 21, 333–353.
13. Duncker, K. (1945). On problem solving. Psychological Monographs, 58:5 (Whole No. 270)
14. Egopont http://web.archive.org/web/20110625092320/http://egopont.com/iq/testpage.php
15. Eshet-Alkalai, Y. (2004). Digital literacy: A conceptual framework for survival skills in the digital era. Journal of Educational Multimedia and Hypermedia, 13(1), 93–106.
16. Fluency Addition to NAAL (FAN). (n.d.). Retrieved from http://nces.ed.gov/naal/fluency.asp
17. Gandhi, R., Veeraraghavan, R., Toyama, K., & Ramprasad, V. (2009). Digital green: Participatory video for agricultural extension. Information Technologies & International Development, 5(1), 1–15.
18. Government of Karnataka, India, Karnataka State Board, Published 2008.
19. Gorham, D. R. (1956). A proverbs test for clinical and experimental use. Psychology Reports. 2, 1-12
20. Goodenough, F. (1926). Measurement of intelligence by drawings. New York: World Book Co.
21. Grisedale, S., Graves, M., & Grünsteidl, A. (1997). Designing a graphical user interface for healthcare workers in rural India. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (pp. 471–478). Atlanta, GA: ACM.
22. Irwing, P. and Lynn, R. (2005), Sex differences in means and variability on the progressive matrices in university students: A meta-analysis. British Journal of Psychology, 96: 505–524.
23. Huenerfauth, M. (2002). Developing design recommendations for computer interfaces accessible to non-literate users. (Master's thesis, University College Dublin).
24. Jones, M. and Marsden, G. (2005) "Mobile Interaction Design" John Wiley & Sons.
25. Jones, M., Buchanan, G., Thimbleby, H., & Marsden, G. (2000). User interfaces for mobile web devices. [www9 mobile workshop position paper]. Proceedings of the 9th International World Wide Web Conference. Amsterdam.
26. Katre, D. S. (2006). Unorganized cognitive structures of non-literate as the key factor in rural e-learning design. I-Manager's Journal of Education Technology, 2(4), 67–72.
27. Kress, G., & Van Leeuwen, T. (1996). Reading images: The grammar of visual design. London: Routledge.
28. Kurvers, J. (2002). Met ongeletterde ogen. Kennis van taal en schrift van analfabeten. [With nonliterate eyes. Knowledge of language and writing of non-literates]. (Thesis, Tilburg University).
29. Ladeira, I. & Cutrell, E. (2010). Teaching with storytelling: An investigation of narrative videos for skills

training. Proceedings of ICTD 2010, the 4th ACM/IEEE International Conference on Information and Communication Technologies and Development, (London), IEEE.

30. Lowell, W. E. "An Empirical Study of a Model of Abstract Learning," Science Education, 61:229-42 (1977).
31. Luria, A. R. (1974). Cognitive development: Its cultural and social foundations. Cambridge, MA: Harvard University Press.
32. Manly, J. J., Touradji, P., Tang, M. X., & Stern, Y. (2003). Literacy and memory decline among ethnically diverse elders. Journal of Clinical and Experimental Neuropsychology, 25, 680–690.
33. Matute, E., Leal, F., Zarabozo, D., Robles, A., & Cedillo, C. (2000). Does literacy have an effect on stick construction tasks? Journal of the International Neuropsychological Society, 6, 668–672.
34. Medhi, I., & Toyama, K. (2007). Full-context videos for first-time, non-literate PC users. IEEE/ACM International Conference on Information and Communication Technologies and Development, Bangalore, India.
35. Medhi, I., Cutrell, E., & Toyama, K. (2010, March 20–24). It's not just illiteracy. India HCI / Interaction Design & International Development, Mumbai.
36. Medhi, I., Menon, S.R., Cutrell, E. & Toyama, K. Correlation between Limited Education and Transfer of Learning, in Information Technologies and International Development, vol. 8, pp. 51-65, June 2012
37. Medhi, I., Patnaik, S., Brunskill, Gautama, S.N.N., Thies, W. and Toyama, K. Designing Mobile Interfaces for Novice and Low-Literacy Users, in ACM ToCHI, vol. 18, no. 1, ACM Transactions on Computer-Human Interaction, April 2011
38. Medhi, I., Sagar, A., & Toyama, K. (2007). Text-free user interfaces for illiterate and semiliterate users. Information Technologies & International Development, 4(1), 37–50.
39. Mednick, S.A. (1962). The associative basis of the creative process. Psychological Review, 69, 220-232.
40. Morais, J., Cary, L., Alegria, J., & Bertelson, P. (1979). Does awareness of speech as a sequence of phones arise spontaneously? Cognition, 7, 323–331.
41. National Adult Literacy Database (NALD). (n.d.). Literacy and basic skills assessment tool from the National Adult Literacy Database Canada. Retrieved from http://www.nald.ca/library/learning/learncha/learncha.pdf
42. National Assessment of Adult Literacy (NAAL). (n.d.). Retrieved from http://nces.ed.gov/naal/index.asp
43. National Literacy Mission (NLM). (n.d.). Retrieved from http://www.nlm.nic.in/unesco_nlm.htm
44. National Sample Survey Organization (NSSO). (n.d.). Retrieved from http://www.literacy.org/products/ili/pdf/LAPIndiaApp_all.pdf
45. Nov, Oded & Arazy, Ofer. (2013). Personality-targeted design: Theory, experimental procedure, and preliminary results. Proceedings of Computer Supported Collaborative Work 2013.
46. Parikh, T., Ghosh, K., & Chavan, A. (2003a, April 5–10). Design considerations for a financial management system for rural, semi-literate users. ACM Conference on Computer-Human Interaction, Fort Lauderdale, Florida, USA (pp. 824–825).
47. Plauche, M., & Prabaker, M. (2006). Tamil market: A spoken dialog system for rural India. Working papers in ACM Conference on Computer Human Interaction, Montreal.
48. Raven, J. C. (1936). Mental tests used in genetic studies: The performance of related individuals on tests mainly educative and mainly reproductive. MSc Thesis, University of London.
49. Raven, J. (1981). Manual for Raven's Progressive Matrices and Vocabulary Scales. Research Supplement No.1: The 1979 British Standardisation of the Standard Progressive Matrices and Mill Hill Vocabulary Scales, Together With Comparative Data From Earlier Studies in the UK, US, Canada, Germany and Ireland. San Antonio, TX: Harcourt Assessment
50. Reis, A., & Castro-Caldas, A. (1997). Illiteracy: A bias for cognitive development. Journal of International Neuropsychological Society, 3, 444–450.
51. Reis, A., Petersson, K. M., Castro-Caldas, A., & Ingvar, M. (2001). Formal schooling influences two- but not three-dimensional naming skills. Brain and Cognition, 47(3), 397–411.
52. Rushton, J. P., Skuy, M., & Bons, T. A. (2004). Construct validity of Raven's Advanced Progressive Matrices for African and non-African engineering students in South Africa. International Journal of Selection and Assessment, *12*, 220-229.
53. Sarva Shiksha Abhiyan http://ssa.nic.in/
54. Sherwani, J., Ali, N., Mirza, S., Fatma, A., Memon, Y., Karim, M., et al. (2007, December 15–16). HealthLine: Speech-based access to health information by low-literate users. IEEE/ACM International Conference on Information and Communication Technologies and Development, Bangalore, India.
55. Study Guide Zone. (n.d.). Test of Adult Basic Education (TABE). Retrieved from http://www.studyguidezone.com/tabetest.htm
56. UN News Centre. (2011, September 8). Literacy vital for beating poverty and disease and reinforcing stability. Retrieved from http://www.un.org/apps/news/story.asp?NewsID_39485&Cr_literacy&Cr1_
57. Van Linden, S., & Cremers, A. H. M. (2008, July 9–11). Cognitive abilities of functionally non-literate persons relevant to ICT use. International Conference on Computers Helping People with Special Needs. Linz, Austria (pp. 705–712).
58. Walton, M., Marsden, G., & Vukovic, V. (2002, April 20–25). Visual literacy as challenge to the internationalization of interfaces: A study of South African student web users. CHI '02 extended abstracts on human factors in computing systems, Minneapolis, MN (pp. 530–531).