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Children's Sleep, Sleepiness, and Performance on Cognitive Tasks

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Abstract

While causal connections between sleep deprivation and attention, learning, and memory have been well established in adults, much less research has been done with children. Relations between the amount and quality of sleep and daytime sleepiness have been found for a number of cognitive and academic tasks in several groups of children. These relations have been found for children who have sleep disorders, for children with disorders involving cognitive impairment, and for typically developing children with no known disorders. The research is reviewed here with a focus on the types of cognitive and academic tasks that have been related to insufficient sleep. A series of studies is described that relates sleep parameters to the Woodcock-Johnson® III Tests of Cognitive Abilities and other, similar measures. Implications for educators and psychologists who work with children are discussed.

Performance by children and adolescents on tests that require attention, memory, reasoning, and other cognitive processes is affected by the quality, quantity, and consistency of their sleep (Sadeh, 2007). While this hypothesis may seem obvious to some, sleep has been rarely considered as an important source of inter- and intra-individual differences in the cognitive and academic performance of children. Recent findings by sleep researchers have clarified the relations between sleepiness and performance, and there are enormous implications for psychological and educational assessment and for academic achievement in children. The effect of sleep insufficiency on attention, learning, and memory may be among the primary causes of children's failure to attain expected learning objectives, and may further be related to behavioral and emotional maladjustment, which may interfere with school achievement (Buckhalt, 2011).

Considerable effort has been exerted by educators, associated professionals, and parents to boost school achievement. Aggregate achievement data, which shows lower than expected results, has long been a source of concern for other groups, including legislators, policymakers, business leaders, and the general public. Failure on the part of teachers and schools has often been blamed for low achievement, accompanied by demands from numerous groups for school reform. Additionally, low achievement has been attributed to failures in parenting, and the various undermining influences of contemporary society (e.g.,

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drugs, poverty, and the distractions of technology). Further, children themselves have been blamed, with some researchers even claiming that immutable genetic differences may be the root cause of low achievement (Jensen, 1969).

While the hypothesis considered here does not negate the influence of any of those sources, it directs attention to a new factor (i.e., sleepiness). It is one thing to locate causes of underachievement; it is quite another to implement remedial interventions that are effective, practical, and economical. Improving children's sleep holds promise as a novel focus for intervention. In this paper, the essential theoretical framework and concomitant empirical evidence for the hypothesis will be reviewed. Implications for prevention and treatment, appropriate for both professionals and laypersons, will be explored.

Sleep and Cognition in Adults

The preponderance of all sleep research to date has addressed the problems of adults who have one or more of the numerous sleep disorders. For example, adults with restless legs syndrome, sleep apnea, and other disorders manifest problems in many domains of functioning, including cognition (Haensel et al., 2009; Pearson et al., 2006). Great interest has also been shown in the impact of sleep and cognitive performance on individuals (often referred to as “shift workers”) who work during the night and sleep during the day, and on other groups, such as military and commercial pilots (Folkard, 2008; Van Dongen, 2006).

Data collected over two decades definitely prove the deleterious effects of sleep deprivation in healthy adults. Conclusions are based partly on experimental studies, during which either adult volunteers stayed awake for extended periods of time (total sleep deprivation), or adults’ sleep periods were restricted to less than typical lengths of sleep (6 to 8 hours; partial sleep deprivation). The evidence clearly shows that losing sleep results in diminished processing ability in multiple areas of cognitive functioning. Lim and Dinges (2010) conducted a meta-analysis of the impact of short-term sleep deprivation on cognitive tasks. Seventy studies, which included a total of 147 cognitive tasks, met the methodologically rigorous criteria. Tasks were categorized into the following cognitive domains: simple attention (e.g., simple reaction time), complex attention (e.g., Stroop test; Stroop, 1938), processing speed (e.g., Digit Symbol-Coding, *Wechsler Adult Intelligence Scale®–Fourth Edition*; Wechsler, 2008), working memory (e.g., Sternberg memory task; Sternberg, 1966), short-term reasoning (e.g., *Wechsler Memory Scale®–Fourth Edition*; Wechsler, 2009), and reasoning and crystallized intelligence (e.g., Mill Hill Vocabulary Scale and Standard Progressive Matrices, *Raven's Standard Progressive Matrices*; Raven, 1998). In the majority of the research, cognitive tasks were used most frequently in experimental studies of learning and memory, where the goal is to measure a given cognitive process as simply and purely as possible. In these studies, normative data are rarely of interest. Accordingly, no study including a battery of norm-based tests, such as the *Woodcock-Johnson III Normative Update* (WJ III® NU; Woodcock, McGrew, & Mather, 2001, 2007a), Wechsler, or *Stanford-Binet Intelligence Scales, Fifth Edition* (SB5; Roid, 2003), was available.

Simple attention showed the largest decrease in performance with a Hedges's g value of –0.776 ($p < .001$); moderate deleterious effects were seen for complex attention ($g = –0.479$;

$p < .001$) and working memory ($g = -0.555$; $p < .001$); and processing speed showed significant, yet smaller effects ($g = 0.302$; $p < .001$). No significant deleterious effects were found for tasks measuring reasoning and crystallized intelligence.

Using these results, Lim and Dinges (2010) tried to determine which of three hypotheses best fit the data: the controlled attention hypothesis, the neuropsychological hypothesis, or the vigilance hypothesis. The controlled attention hypothesis proposes that monotonous, less engaging tasks are easy to perform, but they require some top-down monitoring for optimal performance. The neurological hypothesis rests on the premise that sleep deprivation is particularly disruptive to efficient processing in the prefrontal cortex (PFC), an area of the brain considered to be the seat of executive processing and working memory (Walker & Stickgold, 2006). The vigilance hypothesis says that a sufficient degree of arousal is necessary for the performance of some tasks, and lowered arousal comes with insufficient sleep. While Lim and Dinges point out that these hypotheses are not mutually exclusive, they found the most support for the disruptive effect of sleep deprivation on tasks requiring sustained attention and vigilance (the vigilance hypothesis). The effects are robust and they can manifest quickly, after just a single sleepless night, with important ramifications for automobile, bus, and truck drivers; pilots and air traffic controllers; police officers; and shift workers in factories, among others.

Moderate effects were found for working memory and executive processing, and these results are consistent with recent neuroimaging studies showing that communication between the PFC and the hippocampus, the seat of long-term memory consolidation, occurs during sleep and is relatively absent with sleep deprivation (Gais et al., 2007; Walker & Stickgold, 2006). The negative findings for “higher order” tasks may mean that while long-term storage and higher-order processing are built upon the scaffolding of attention and executive processing, adults are capable of engaging compensatory processes that enable access of long-term memory and fluid reasoning, even in the context of deprived sleep.

It is important to consider the participants of these studies were presumably healthy adults who were free of clinical sleep disorders and had no chronic sleep insufficiency. While sleep restriction over a period of a few days or one to two weeks has been studied (Dinges, Rogers, & Baynard, 2005), the effects of insufficient sleep over many weeks, months, and years has not yet been explored.

Sleep and Cognition in Children

Research indicates children also have cognitive dysfunctions that are related to their sleep. As is the case with adults, children with many clinical-level sleep disorders tend to perform relatively poorly on cognitive tasks (Beebe, 2006). To cite an example, obstructive sleep apnea (a condition that causes intermittent hypoxia and disruption of sleep) has been associated with poor performance on cognitive tasks (Kheirandish & Gozal, 2006). Notably, interventions that are successful in treating sleep disorders have been associated with improved cognitive functioning (Chervin et al., 2006; Montgomery-Downs, Crabtree, & Gozal, 2005).

Conversely, groups of children with numerous learning disorders have an elevated prevalence of sleep problems. For children with intellectual disabilities, estimates indicate that up to 80% suffer from sleep difficulties (Richdale, Francis, Gavidia-Payne, & Cotton, 2000). Between 40% and 80% of children with autism have sleep problems (Williams, Sears, & Allard, 2004), and between 25% and 50% of children with attention-deficit/hyperactivity disorder (ADHD) experience problems with sleep (Cortese, Farone, Konofal, & Lecendreux, 2009).

Research with healthy children has been less extensive than research with healthy adults for a variety of reasons, including more restrictive conditions for obtaining consent for participation, and ethical issues pertaining to depriving children of sleep. Studies involving children, with only a few exceptions, have incorporated correlational designs. A small number of studies have found decrements in cognitive and academic measures following limited restriction of sleep (i.e., allowing children one hour less per night; Sadeh, Gruber, & Raviv, 2003), but these manipulations are in no way comparable to the partial or total sleep deprivation studies in adults.

Reviews of this body of research have been published recently in *Sleep Medicine Reviews*. One review focused on laboratory measures of memory (Kopasz et al., 2010), and another review was a meta-analysis of studies that included broader measures of school performance, including grades, standardized tests, and self- or parent-reports (Dewald, Meijer, Oort, Kerkhof, & Bögels, 2009). Kopasz et al. (2010) identified 15 studies and found that, contrary to the results with adults, performance on abstract and complex tasks in children showed greater relations with sleep than simple memory tasks. Children may lack the compensatory skills presumably applied by adults to mitigate the effects of poor sleep.

Dewald et al. (2009) reviewed 16 studies and concluded effect sizes of relations between various school and sleep measures were significant, yet modest in size. For example, a small overall effect size ($z = -0.135$; $p < .001$) was found for studies of sleepiness and school performance. Age was a significant moderator ($\beta = 0.823$; $p < .001$), in that larger effects were found for studies including younger participants, and larger effects were seen for parent-reported sleep than for other, objective measures.

It should be noted that no single study was included in both reviews. However, in both reviews, the authors emphasized that effects need to be considered in light of the possible moderation influences of several variables, including the developmental stage of children, socioeconomic status, and sex. Taking these and other potential factors into account may yield larger correlations between sleep and the interdependent variables studied.

The next challenge for researchers is to clearly identify the cognitive functions and the related concomitant brain areas that are most affected when children's sleep is of insufficient length or poor quality. Further, better understanding about which stages of sleep are most critical for affecting various behavioral outcomes is needed. Related to those questions is whether the correlations observed for narrow, experimental, cognitive tasks are also observed on measures conventionally used to assess school performance, including subtests of standardized batteries and objective measures of academic achievement. It is equally important to determine how short-term versus chronic sleep insufficiency is related to various measures of cognitive functioning and achievement in school. Long-term, untreated sleep disturbances have serious deleterious consequences, including deterioration of neuronal functions (Jan, Reiter, Bax, Ribary, Freeman, & Wasdell, 2010), cardiovascular health, and the immune system (Mullington, Haack, Toth, Serrador, & Meier-Ewert, 2009).

Longitudinal studies have been scarce, and such studies are vital to understanding how early sleep patterns in children are related to later performance outcomes. Especially important is research that focuses on sleep during the period of pubertal onset, because considerable research has shown that sleep patterns change, sometimes markedly, during that transition (Carskadon, Acebo, & Jenni, 2004). Transition to puberty corresponds to the middle and junior high school grades in the United States, where social factors combine with physiological changes to present a unique set of challenges for adolescent students, their parents, and their teachers.

In light of the considerations identified above, we have conducted research in our laboratory with the following objectives:

1. Assessment of cognitive functioning and academic achievement using
    - a. Tests from the *Woodcock-Johnson III Tests of Cognitive Abilities* (WJ III COG; Woodcock, McGrew, & Mather, 2001, 2007b)
    - b. Reaction time tasks
    - c. Standardized achievement tests
2. Evaluation of sleep parameters, including self- and parent-report measures, sleep diaries, and actigraphy
3. Longitudinal assessment of groups of children over several years
4. Inclusion of children from differing racial/ethnic groups, across a wide range of socioeconomic statuses

The emphasis in this paper is how sleepiness relates to cognitive and academic outcomes in children. Additional interests include relationships between children's sleep and behavioral and emotional adjustment (El-Sheikh, Buckhalt, Cummings, & Keller, 2007; El-Sheikh, Kelly, Buckhalt, & Hinnant, 2010), assessed not only with conventional parent and teacher report measures, but also with measures of physiological response (e.g., skin conductance reactivity and vagal nerve regulation) and bio-behavioral markers including cortisol (El-Sheikh, Buckhalt, Keller, & Granger, 2008), Interleukin-6 (IL-6; El-Sheikh, Buckhalt, Granger, Erath, & Acebo, 2007), and alpha-amylase (Granger et al., 2006). These studies will not be described here, but they are relevant to the general topic of school performance as behavioral and emotional adjustments of children make their independent and interactive contributions to children's performance in school.

Method

Participants

The participating children and families reside in the mostly rural and suburban areas surrounding Auburn University, a large state university located in a small town in east central Alabama. Children were selected in representative proportions corresponding to the two racial/ethnic groups that predominate the area: Euro-American (EA; ~70%), and African-American (AA; ~30%). A primary variable upon which samples were selected was the socioeconomic status (SES) of families. The goal was to attain an even distribution of SES across both racial/ethnic groups to reduce SES and racial/ethnic confounding.

Procedures

For one week, children wore an actigraph, which measures sleep duration and quality, on their wrist when they went to bed, and their parents kept diaries of bedtimes and wake times. The children then came to our lab for completion of additional self-reported sleep measures and cognitive tests. Achievement test scores were obtained directly from the children's school districts.

Assessment with standardized tests commonly used in schools is a unique method compared to previous studies, which primarily use nonstandardized laboratory measures of cognitive functioning. Cognitive assessment in our studies included six tests of the WJ III COG: Test 1: Verbal Comprehension, Test 5: Concept Formation, Test 6: Visual Matching, Test 7: Numbers Reversed, Test 9: Auditory Working Memory, and Test 16: Decision Speed. These tests were selected to ensure the appropriate scores were available to create the targeted clusters.

Clusters are composed of tests; four clusters were the main focus of this study. The clusters included Brief Intellectual Ability (BIA) (i.e., Verbal Comprehension, Concept Formation, and Visual Matching tests), Processing Speed (i.e., Visual Matching and Decision Speed tests), Working Memory (i.e., Numbers Reversed and Auditory Working Memory tests), and Cognitive Efficiency (i.e., Visual Matching and Numbers Reversed tests). These tests allow the assessment of functioning in areas that have received attention in previous sleep research with children (e.g., working memory) along with areas that have not been assessed very often (i.e., fluid ability measured by Concept Formation, and crystallized intelligence measured by Verbal Comprehension).

While there would be advantages of using an even more extensive set of WJ III COG assessments, considerations of time required for the lab visit influenced selection of the measures. In addition to WJ III COG tests, children used a personal computer to complete reaction time tasks that measured simple and choice reaction time, including evaluating both speed and variability of response. School districts provided, with parental permission, scores from the *Stanford Achievement Test Series, Tenth Edition* (Stanford 10; 2000).

Analyses of data have included multiple regression, path analysis and structural equation modeling with tests for moderator variables, and latent growth curve analysis.

Results

Primary Research Findings

Rather than describe results of each study in detail, the primary findings are summarized with citations of published papers that can be referenced for comprehensive results.

1. Several sleep parameters were related to the WJ III COG test and cluster scores, and the relations were found to be different, depending on racial/ethnic group and SES. Briefly, in the context of longer, better quality, or more consistent sleep, Euro-American and higher SES children's scores were higher on a number of WJ III COG clusters, including Processing Speed, Verbal Ability, Working Memory, and Brief Intellectual Ability (Buckhalt, El-Sheikh, & Keller, 2007).
2. In a two-year follow-up with the same children, the findings showed many cognitive variables were related not only to concurrently assessed sleep, but also to sleep two years earlier. These included the clusters of Processing Speed, Cognitive Efficiency, Verbal Ability, and Brief Intellectual Ability from the WJ III COG as well as Language, Reading, and Mathematics achievement subtests from the Stanford 10. Significant moderation effects for SES were discovered similar to those found during the initial assessment two years earlier (Buckhalt, El-Sheikh, Keller, & Kelly, 2009).
3. A different sample of demographically similar children was studied over three years, from 3rd grade to 5th grade. The study was the first of its kind in that (a) assessment was conducted over the span of three years, and (b) the study allowed for relations between rates of change in both sleep and cognitive measures. Strengths of associations between sleep and cognitive functioning increased over time, and rates of change in both domains were related. Among the findings were that children who reported increases in sleepiness over time showed little increase in verbal comprehension (WJ III COG Test 1: Verbal Comprehension) compared to those who reported a decrease in sleepiness, resulting in a difference of about 11 scaled score points by grade 5. African-American children showed particular vulnerability for poor cognitive outcomes in the context of increased sleepiness, with 16- to 19-point lower scores. Relations between changes in sleep and cognitive performance were found to differ between boys and girls independent of SES and race/ethnicity. Sleepiness affected girls' performance more than boys' performance. By grade 5, girls who reported increased sleepiness had scores 11 to 19 points lower than girls who reported decreases in sleepiness. (Bub, Buckhalt, & El-Sheikh, 2011).

Discussion

As in adults, we have confirmed that measures of processing speed and working memory are related to sleep (Lim & Dinges, 2010). But unlike the preponderance of adult data, "higher-level" processes, including verbal and general intelligence, were linked to sleep of the children in our studies. Moreover, sleep was also related to performance on standardized measures of school achievement. While sleep-deprived adults may be able to use compensatory processing skills on tests that require reasoning and access to long-term memory, developing children may be less able to do so.

It is important to recall that sleep insufficiency in our samples was relative, distributed along a presumed normal continuum, and the adult studies reviewed by Lim and Dinges (2010) involved deliberate sleep deprivation. We might reasonably expect that the connections discovered for children might be even greater in the context of true sleep deprivation. Further, inclusion of children with sleep disorders or intellectual disorders would likely result in strengthened connectivity, given the well-established findings of comorbidity of these conditions (Kheirandish & Gozal, 2006; Richdale, Francis, Gavidia-Payne, & Cotton, 2000).

Of great concern is our finding that when relations between sleep and cognitive functioning are compared in the same children studied over several years, those relations become stronger. One sobering possibility is that children may accumulate sleep debt on a regular basis, and over time, develop a chronic state of sleep insufficiency. Most alarming was that young, school-age children in our samples had measured nightly sleep durations of around 7.5 hours, far shorter than the 9 to 10 hours recommended by pediatricians (National Sleep Foundation, 2004).

The findings with regard to race/ethnicity and SES have led us to propose a novel hypothesis: Some portion of the widely acknowledged and persistent achievement gap may be related to insufficient sleep during the developmental period (Buckhalt, 2011; Buckhalt & Staton, 2011). Many hypotheses have been investigated over the past 50 years to determine why lower SES children show lower achievement levels than their higher SES counterparts. Among the possible causes for this lower achievement include (a) lack of the “head start” that advantaged children have coming into school, (b) low quality schools, (c) ineffective teachers, (d) inherent lower learning ability, (e) inadequate nutrition, (f) slow socialization to the school setting, and (g) insufficient parental monitoring and school involvement. Support for the sleep hypothesis does not exclude other causes, and there are undoubtedly multiple factors that interact dynamically. But if sleep accounts for any significant proportion of the variance in school achievement, improving children's sleep may provide a new focus to narrow the achievement gap.

The finding of greater vulnerability in girls for poor sleep related to cognitive performance is intriguing and deserves further study. Much research has shown that when adolescents begin puberty, there is a phase delay in sleep patterns, and children may experience more difficulty in falling asleep early in the evening and more difficulty waking early in the morning (Carskadon, Acebo, & Jenni, 2004). Given that girls enter puberty, on average, earlier than boys, the earlier onset phase delay may be associated with sex-related sleep differences. While there is less evidence for sex differences than for different SES and racial/ethnic groups, sleep could be related to different sex patterns of achievement in academic areas. A sex gap in science and mathematics has long been observed, with much research devoted to discovering the causes and ways to reduce or eliminate the differences (Benbow, Lubinski, Shea, & Eftekhari-Sanjani, 2000). Further study of sleep may cast a new light on underlying mechanisms of these differences.

Many questions remain regarding how children's sleep is related to their cognitive functioning abilities at school. Further research may include:

1. Replications and extensions in our lab and in other labs with other samples
2. Reliance on "natural experiments" to study sleep deprivation in children including measuring sleep and cognitive functioning after sleepovers and other occasions when children elect to restrict the length and quality of their sleep
3. Replication and extension of the few studies that have incorporated true experimental designs involving restriction (and extension) of sleep
4. Using single-subject designs to track the relations of sleep and cognitive performance on a day-to-day basis
5. Measurement of sleep over longer periods of time
6. Determining, through polysomnography, which stages of sleep influence different areas of cognitive functioning
7. Investigation of group and individual differences in the relations discovered to date
8. Explorations of how socioemotional and cognitive functions are jointly related to sleep
9. Intervention studies with both individual children and groups of children

Implications for Educational and Psychological Practice

Why should educators be concerned about the relations between sleep and school performance? It is no doubt common knowledge that many children are periodically sleepy at school. Many may assume that sleep disorders, such as apnea, are relatively uncommon in children and thus likely to affect only a small number of cases. Further, some will question whether sleepiness can be a significant contributor to low achievement within the context of numerous other causes that have already been investigated.

Amounts of sleep reported by children, adolescents, and their parents has shown a troubling downward trajectory over recent years in a number of European countries as well the United States and Australia (National Sleep Foundation, 2004, 2006; Olds, Blunden, Petkov & Forchino, 2010). Most people, adults and children alike, are thought to be sleeping less, and sleeping less well, than in the past. While cultural evolution is rapid, the roots of our circadian rhythm are as ancient as life itself. Electric lighting is a relatively recent invention in history, and in the preceding millennia, people were more inclined to sleep for longer periods during the night. The lessening of the amount of time spent sleeping has been driven very gradually by a host of factors. Some of these factors, related directly to ongoing development of technology, include 24-hour television, the Internet, and mobile telephone access. Other factors include consumer businesses that are open 24 hours a day in many instances (e.g., grocery stores, gasoline stations, and restaurants) or have extended nighttime hours, and organizations that operate three work shifts (e.g., military facilities, factories, and hospitals). As a result of these changes, many people, children included, are engaged in a far greater number of activities over the course of the artificially "extended" day than in the recent past. These changes have been slow and insidious, and the analogy of a frog unknowingly dying in water heated gradually to a boil is apropos. Sleep has been reduced slowly, almost imperceptibly, and, as a result, numerous aspects of our health and well-being have been compromised.

Finally, while much more remains to be understood about the relations of sleep and cognitive development in children, the existing body of research illuminates many implications for practices that can be put into place now. A few of these are as follows:

1. Authors, publishers, and administrators of psycho-educational assessments must recognize that sleepy children do not respond optimally to tests; this awareness adds a new area of concern about the validity of test results and conclusions drawn from these results. Examiners need to learn to recognize when children are sleepy and take appropriate action. Some of these include (a) testing at a different time of day, or another day, when the child is not sleepy, if possible; (b) noting the child's sleepy status in the behavioral observations section of the report; and (c) considering sleepiness in formulating conclusions about core reasons for a child's poor performance and the need for interventions.

2. Sleep problems should be ruled out as a major source of dysfunction before reaching a diagnosis of any learning or behavioral/emotional disorder. Comorbidity of sleep problems and other diagnoses (e.g., anxiety, depression, and intellectual disability) should be evaluated. Many children with concurrent diagnoses should be revaluated with new attention given to the role of sleep as a cause and/or outcome of the existing diagnosis.

3. Educators and clinicians should begin to incorporate sleep problem prevention and intervention into their treatment plans. Sleepy children are not likely to be responsive to instruction. Incorporation of sleep interventions into individualized education or treatment plans may yield significant gains in school achievement.

4. Health education in schools should include information and instruction about sleep and how it relates to health and academic achievement.

5. Parents should be prepared to adopt and enforce lifestyle changes so their children's sleep is sufficient for healthy development, learning, and adjustment. These include changing patterns of behaviors (e.g., disallowing late night activities, and keeping noise levels down after children's bedtimes) and changing physical aspects of the home environment that affect sleep (e.g., improving beds, bedding, and bedroom air quality).

6. Members of society other than parents, teachers, and health professionals should understand the importance of children's sleep, and take care not to create situations that impede consistent and restful sleep (e.g., not scheduling athletic events for children on school nights).

None of these recommendations are likely to be implemented easily or quickly. But in the not too distant past, the idea of serving breakfast to children at school was controversial and thought to be difficult to implement, logistically and financially. Once it was generally acknowledged that hungry children are not optimally responsive to instruction, barriers were overcome to implement a solution. Now, evidence exists that indicates many of our children come to school sleepy, and their performance suffers due to this sleepiness. We should rise to meet the challenge before us as the evidence about the relations between lack of sleep and performance on cognitive tasks in children continues to accumulate, and the issue is eventually widely disseminated and understood.

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