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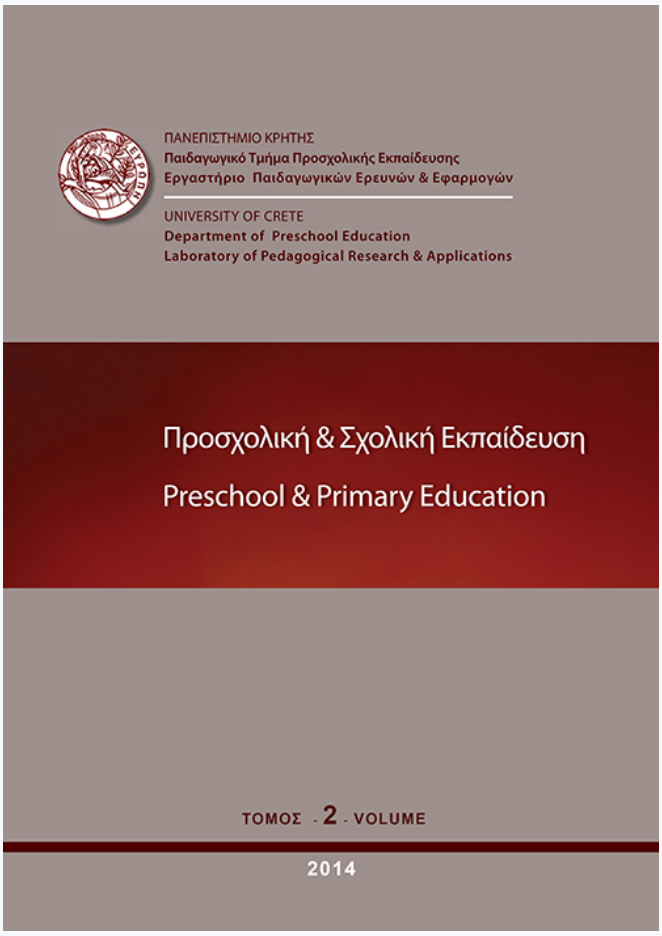

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Themistocles Tsikalas, Dimitrios Stamovlasis, George Papageorgiou

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Mental representations of 12 year-old children about boiling and evaporation: A probabilistic association with convergent and divergent thinking

Themistocles Tsikalas
Democritus University of Thrace

Dimitrios Stamovlasis
Aristotle University of Thessaloniki

George Papageorgiou
Democritus University of Thrace

Summary. Students' understanding of physical phenomena is determined by their relevant representations, which are very crucial for science education. Since these representations are often incompatible with the scientific view, their functional role in the learning processes has been the main interest of a plethora of research work over the last decades. In the present research students' representations for boiling and evaporation are investigated and an attempt is made to correlate them with two cognitive variables, which have been shown to be involved in mental processes of learning science, namely convergent and divergent thinking. The study took place with the participation of 375 sixth-grade elementary school pupils (aged 11-12). Methodologically the ordinal logistic regression was implemented to correlate the categorical-type dependent variable with scale-type independent predictors. The results show that both convergent and divergent thinking are significantly associated with pupils' sufficient responses. Interpretation of the results and implications for science education are discussed.

Keywords: Misconceptions, cognitive variables, boiling, evaporation, convergence/divergence, ordinal logistic regression.

Introduction

Students' understanding of physical phenomena has been one of the central focuses in science education research over the last decades (e.g. Bar & Galili, 1994; Lee, Eichinger, Anderson, Berkheimer, & Blakeslee, 1993; Hatzinikita & Koulaidis, 1997; Johnson, 1998b,c; Coştu & Ayas, 2005; Papageorgiou & Johnson, 2005; Stamovlasis, Papageorgiou & Tsitsipis, 2013). Relevant difficulties and misconceptions appear to be present in a wide range of ages, although there is a cross-age progress. In primary pupils, problems seem to be more extended, especially in changes involving the gas state such as boiling and evaporation (e.g. Hatzinikita & Koulaidis, 1997; Papageorgiou & Johnson, 2005; Tytler, 2000, Paik, Kim, Cho & Park, 2004). According to some researchers (e.g. Stavridou & Solomonidou, 1998; Johnson,

Corresponding author: *George Papageorgiou*, Department of Primary Education, Democritus University of Thrace, Greece, e-mail: gpapageo@eled.duth.gr

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1998a, 1998b; Papageorgiou & Johnson, 2005) this originates from the lack of an understanding of the concept of substance itself; if one cannot understand the 'substance', one is unlikely to understand its changes. From Piagetian point of view, this is expected to a certain degree, since 'substance' is an idea based on the particle theory, which is too difficult for those ages, as it involves late formal thinking. As a result, in many countries, including Greece, physical phenomena are taught basically at the macroscopic level. However, teaching these phenomena on such a basis is a deficient prescription (Johnson & Papageorgiou, 2010), which cannot effectively eliminate students' relevant misconceptions.

In particular, students' misconceptions about boiling mainly concern the basic idea of such a change of state, including the content of the bubbles, especially in young ages, whereas in elder ages problems have also been identified in the factors that influence the boiling point and the effect of vapour pressure (Coştu, Ayas, & Niaz, 2010). Primary pupils usually cannot connect the content of the bubbles inside the water with that of the steam above the surface of boiling water (when the liquid is water) and they often hold alternative representations where boiling is the process in which bubbles are formed in a static system without the concept of a change of state. Thus, they cannot recognize the diminution of the level of the liquid state during boiling, whereas air, heat, carbon dioxide, a mixture of hydrogen and oxygen, or other materials are included in their responses about the content of the bubbles (e.g. Hatzinikita & Koulaidis, 1997; Johnson, 1998b, 1998c).

As far as evaporation is concerned, there are again misconceptions, including the conservation of matter during the phenomenon, the role of the nature of the substances involved, the effect of temperature, or distinguishing it from the concept of boiling, whereas in elder ages, misconceptions about evaporation shift to closed systems where the role of vapour pressure and other factors are under study (Coştu, Ayas, Niaz, Ünal, S., & Çalik, 2007).

When young pupils recognize the phenomenon, they tend rather to accept that the evaporated substance disappeared without any particular explanation, or to naively justify it (usually as an absorption by the container or a transformation of the evaporated substance into air), than to accept evaporation as a mixing phenomenon involving air (e.g., Hatzinikita & Koulaidis, 1997; Tytler, 2000; Papageorgiou & Johnson, 2005).

Looked at from another angle, the main focus of research in science education, such as the above, was almost exclusively on the difficulties arising from the peculiarities of the subject matter itself, without attempting to explain the variability in students' representations with independent variables. However, persistent misconceptions by students and alternative ideas are products of cognitive processes where a variety of mental resources are involved. Some of them are related to convergent and divergent thinking, which, although not extensively explored in primary pupils, have been shown to be associated with conceptual understanding in secondary science education and particularly with an understanding of the structure of substances and their changes (Danili & Reid, 2006; Tsitsipis, Stamovlasis, & Papageorgiou, 2010).

Convergent and divergent thinking

Convergence (CONV) and divergence (DIV) are two distinct cognitive styles, not mutually exclusive (Heller, 2007), that were introduced as special aspects of intelligence. Convergence is the ability of an individual to focus on the one right answer in order to find the solution to a problem, whereas divergence is one's ability to respond successfully to problems requiring the generation of several solutions with flexibility (Child & Smithers, 1973). Since Gretzels and Jackson (1962) distinguished intelligence from creativity, most researchers have believed that divergent thinking is associated with creativity, whereas convergent thinking is associated with intelligence. In science education research, students' achievement is found to be significantly associated with these psychometric variables (Danili & Reid, 2006; Stamovlasis, Tsitsipis, & Papageorgiou, 2010).

Rationale and research questions

Although cognitive Psychology applied to science education has accumulated a considerable body of knowledge on the role of individual difference in science learning, the majority of the research in science education places no emphasis on the variability in students' competence in connection to such independent variables. In contrast to such research, the present study seeks empirical evidence analogous to that already mentioned for secondary science education (Danili & Reid, 2006; Tsitsipis et al., 2010) and posited the hypothesis that the effect of the above cognitive styles, i.e. convergent and divergent thinking, is also present at younger ages, determining pupils' representations of physical phenomena.

Moreover, methodologically, the current approach considers students' representations that are behind their explanations of physical phenomena as categorical variables and uses ordinal logistic regressions to correlate them with scale –type independent ones. It is worth noting that since logistic regression does not presuppose the distributional assumptions on which the general linear model is based, it constitutes a distinct approach for exploring data and it is appropriate for our analysis.

Thus, the present work aims to investigate:

1 . Students' mental representation of boiling and evaporation and whether they attained the scientific view taking into account what could be expected of students at such ages and what they had been taught in class.

2. The association of students' mental representation with convergent and divergent thinking. Specifically, considering previous findings, it is expected that the odds of possessing a sufficient representation are positively associated with the scales of convergent and divergent thinking.

Methodology

Subjects

The study was conducted with the participation of 375 sixth-grade primary school Greek pupils (age 11-12, 49.1% females). The subjects were of different socioeconomic status and attended 17 different schools in Northern Greece. All subjects had been taught an introductory course in physical science, according to the curriculum, during the previous academic year.

Procedures and Measurements

Data were collected over six months through paper-and-pencil tests. The instruments used are briefly described below.

Divergent Thinking (DIV)

Divergence was measured by a six-item test designed by Bahar (1999). Each item substantially constituted a mini test itself lasting for 2–5 min that asked students: to generate words with similar meaning to those given (test 1), to construct up to four sentences using the words in the form as given (test 2), to draw up to five different sketches relevant to a given idea (test 3), to write as many things as possible that have a common trait (test 4), to write as many words as possible that begin with one specific letter and end with another specific letter (test 5), and to list all the ideas about a given topic (test 6). This instrument was used first with Greek students by Danili and Reid (2006) and by Tsitsipis et al. (2010). A Cronbach's alpha reliability coefficient of 0.74 was obtained for the present study.

Convergent Thinking (CONV)

Convergence was assessed by a five-item timed test, which was introduced recently by Hindal, Reid and Badgaish (2009). The test was translated into Greek with modification to some words and ideas so as to fit Greek idiom. Students were asked to answer each question separately in a total time of 20 minutes. Test 1 asked students: to find two patterns that link to a group of words given (question 1), to form two words from the letters given (question 2) and to write and explain a number missing from three sequences given (question 3). Test 2 asked students to read a topic and classify three main ideas in a diagram given. Test 3 asked students to pick out the different object from a group of four and explain the reason they selected it. Test 4 asked students to write two things~~,~~ which are true for all four graphs given. Test 5 asked students to mark a route on a map and describe the way in a few words. For the present sample the Cronbach's alpha reliability coefficient was found to be 0.77.

Tasks on boiling and evaporation

Pupils' responses were collected by an open-ended questionnaire composed by selecting items utilized in a number of related research studies (Johnson, 1998a, b, c; Papageorgiou, Stamovlasis, & Johnson, 2010). A pilot study followed by interviews was carried out to correct possible communication deficiencies of the test, and to enhance the anticipated research validity. Pupils were asked to fill the research questionnaire one year after they had been taught the relevant material. Thus, the instrument is considered to measure the residual knowledge on this matter. The questionnaire included pictures and figures that facilitated pupils' understanding of the context that the questions referred to. A description of the main tasks of the questionnaire and possible outcomes are presented in Table 1.

Table 1 Description of the tasks and possible outcomes.

Tasks		Description of the tasks	Possible outcomes per task
Boiling	Q1	Pupils were asked to describe what will happen to the level of water in a vessel after boiling for some time	Conservation of the quantity of water in the two states (gas and liquid)
	Q2	Pupils were asked directly what is inside the bubbles (shown in a relevant picture)	Understanding of the content of the bubbles
Evaporation	Q3	Pupils were asked what will happen to a quantity of water left in a plate for some time	Connecting the diminution of water in the plate with the formation of its gaseous state
	Q4	Pupils were asked whether (and why) the phenomenon would happen faster on a cold or on a warm day	Recognizing the effect of temperature on the phenomenon
	Q5	Pupils were asked whether (and why) the phenomenon would happen faster if alcohol were in the plate instead of water	Connecting the nature of a substance with the evaporation rate

Pupils' responses were evaluated by two raters with final agreement (100%) after negotiation. The responses were recorded as categorical data and they were tabulated for the needs of the study. The pupils were asked to provide responses, which were characterized as 'Sufficient' when they were in line with the scientific view to a satisfying degree, taking into account what had been taught and what was expected from those ages. On the contrary, they were characterized as 'Insufficient' when they were clearly incorrect and /or irrelevant, or they included alternative ideas. Some responses that could be considered partially correct but provided no explanation were characterized as 'Intermediate'. Relevant examples are given in the 'Results' section.

Statistical Analysis

In this study, the *ordinal logistic regression analysis (OLR)* was used (Hilbe, 2009). The three-level ordinal variable (level 1 = 'Insufficient', level 2 = 'Intermediate' and level 3 = 'Sufficient') is used as the dependent variable in the *OLR*. In general, the logistic form of this model is defined as the log of the ratio of probability of levels under or equal to a given cut to the probability of those over the cut. This ratio of probabilities is called *odds*, while the $\log_e$ [*odds*] is implemented for the three levels:

Category or level 1 Logit = $\ln[p_1 / (1- p_1)]$

Category or level 2 Logit = $\ln[(p_1 +p_2)/ (1- p_1 - p_1)]$

Category or level 3 Logit = $\ln[(p_1 +p_2 + p_3) / (1- p_1 - p_1- p_3)]$

$$Logit = b_0 + b_1 X \text{ , where X = CONV or DIV}$$

The Z statistic is used, which tests the null hypothesis (Ho) that b=0. The estimated values of b_i's have to be statistically significant and they should not span the zero point. The interpretation of ordered logit coefficient is that, for one unit increase in the predictor, the response variable level is expected to change by its respective regression coefficient in the ordered log-odds scale, *ceteris paribus*. The coefficients b_i's in the OLR are estimated iteratively from the data with maximum likelihood methods by using the *Stata*-software (Hilbe, 2009).

Results

Table 2 shows the frequency of the 'Sufficient', 'Intermediate' and 'Insufficient' responses for the questions related to *boiling* and *evaporation*.

Table 2 Frequency of pupils' responses to the five questions

	Q1	Q2	Q3	Q4	Q5
Sufficient	137	18	55	264	13
Intermediate	123	212	53	23	96
Insufficient	115	145	267	106	266

From Piagetian point of view, the conservation of matter is supposed to be developed to a significant degree by 12 year-old pupils, but there were few 'sufficient' responses to Q1, although this was expected to a certain degree taking into account the results of similar studies (e.g. Hatzinikita & Koulaidis, 1997; Krnel, Watson, & Glazar, 1998). Also, this is justified to a certain degree by the significant number of 'intermediate' responses. Answers such as '*the level of water will be lower... because boiling water will be transformed into vapor and escape*' or '*the level of water will be lower… because the heating process* *transforms water into gas, .. and it leaves the vessel* ' were considered to be 'sufficient', whereas an answer such as ' *the level of water will be lower, bubbles are formed and the water leaves the vessel'* was considered to be 'intermediate'. In contrast, answers such as '*…something goes up…', 'the vessel absorbs the water ...'* or *'the trapped air leaves the vessel'* were considered to be ~~as~~ 'insufficient'.

Frequencies concerning Q2 are rather expected. As already reported, research (e.g. Hatzinikita & Koulaidis, 1997; Papageorgiou & Johnson, 2005) indicate that students cannot connect the content of bubbles with the boiling liquid's change of state. In accordance with these studies, many pupils' answers such as '*the bubbles are heated air*', '*the bubbles are heat*' or '*the bubbles contain oxygen and/or hydrogen*' were categorized as 'insufficient'. Answers such as 'the bubbles are water in gas state' or 'bubbles contain steam' were considered 'sufficient', while answers such as *' it is water'* or *'water is transformed into bubbles…'* were considered 'intermediate'.

Pupils' responses to Q3 were mostly 'insufficient'. In accordance with previous studies (e.g., Osborne & Cosgrove, 1983; Tytler, 2000; Johnson, 1998b, 1998c), representative responses were ' *the water is absorbed by the sun* ', ' *the plate absorbs the water* ', ' *the heat absorbs the water* ' or '*the water does not exist anymore* '. However, a number of pupils' responses such as '*the water has been transformed into a gas and it left the plate ...*' was considered 'sufficient', while an answer such as '*the water becomes small drops and goes up in the air'* was considered 'intermediate'.

Unlike Q3, the 'sufficient' responses to Q4 were quite extended. It seems that pupils are used to connecting evaporation with warm environments, probably due to their everyday experiences. Thus, in accordance with Coştu and Ayas (2005), a great number of them gave 'sufficient' responses such as '*on a warm day, water heats more and it becomes a gas faster*'. Among the 'intermediate' responses were those without any justification such as 'on *a warm day*', whereas 'insufficient' category contained responses such as '*a cold day*' or no particular response~~s~~.

Table 3 Results of the ten ordinal logistic regression models. The estimated coefficients *b*s (Coef.) and standard errors (*S.E.*), Z statistic, *p*-values and 95% confidence intervals.

Question	**Cognitive Variable**	**Coef.**	***S.E.***	***Z***	**95% CI**	
Q1	CONV	0.08333	0.01871	4.45***	0.0466	0.9239
	DIV	0.02945	0.0066	4.43***	0.0164	0.0425
Q2	CONV	0.08127	0.0204	3.98***	0.0413	0.1213
	DIV	0.02454	0.0069	3.53***	0.0191	0.0382
Q3	CONV	0.08866	0.02346	3.78***	0.0427	0.1346
	DIV	0.03100	0.00775	4.00***	0.0158	0.0462
Q4	CONV	0.12763	0.02271	5.62***	0.0831	0.1721
	DIV	0.02994	0.00754	3.97***	0.0152	0.0447
Q5	CONV	0.11322	0.02425	4.67***	0.0657	0.1607
	DIV	0.03152	0.00791	3.99***	0.0160	0.0470

* $p < 0.10$, ** $p < 0.01$, *** $p < 0.001$

As for the pupils' answers to Q5, pupils appeared to be unfamiliar with evaporation of other substances except water. Water fairly has the title of the 'prototype' of all liquids (Krnel et al., 1998). Among the 'insufficient' responses it is worth noting '*only water evaporates (not alcohol)*', '*alcohol is heavier than water it does not evaporate*', '*alcohol does not* *evaporate because it is flammable*' or '*alcohol does not evaporate because it has more power to resist heat*'. Answers such as '*alcohol is more volatile that water*' or a quite common '*alcohol is more light that water and it will became gas faster...*' were considered 'sufficient', while answers such as '*alcohol will became gas faster*' (without explanation) was considered 'intermediate'.

Table 3 shows the results from the ordinal logistic regression (OLR) analysis: The estimated *b*s, their standard deviations and the *Z* statistic for their statistical significance, as well as the 95% confidence intervals are provided.

The statistical analysis in Table 3 shows that both convergent (CONV) and divergent (DIV) thinking are significantly associated with the ordinal response-variable, operationalizing the latent mental representations of students. That is, convergent and divergent thinking correspond to mental resources that are involved in cognitive processes when pupils think about, reflect on, recognize and explain the physical phenomena in question.

Discussion and educational implications

The results of this study verify a number of misconceptions of 12-year-old pupils concerning boiling and evaporation and clearly demonstrate the relation of convergent and divergent thinking with the odds of holding a sufficient mental representation on such phenomena.

Focusing on pupils' misconceptions, it is impressive that, even though the subject material had been taught over the past academic year and the phenomena in question are experienced in everyday life, the percentage of sufficient responses are rather low and vary with the question. For these phenomena, 70-80% of the pupils' responses and their underlying representations are far from the scientific view. From a pedagogical point of view, the difficulties which arise here possibly originate from a number of deficiencies such as the following. As a number of researchers suggest (e.g. Stavridou & Solomonidou, 1998; Johnson, 1998a, 1998b, 1998c; Papageorgiou & Johnson, 2005), pupils~~,~~ who are not aware of the particulate nature of matter cannot understand the concept of a substance and, as a result, they fail successfully to manage its forms and transformations. This could probably explain pupils' insufficient and intermediate representations, concerning the conservation of matter in the liquid state (e.g., Q1), inside the bubbles (Q2) or in the gaseous state (e.g., Q3). It is characteristic that among the pupils' response was the view that boiling is the process where '*the trapped air escapes*'. If one combines this with answers referring to '*air*' as the content of bubbles, it becomes apparent that pupils involve air (considering it a substance) in the change of states of water. Going a little further, we could argue that this also indicates a confusion of boiling with the phenomenon where dissolved air forms bubbles and escapes when temperature rises. However, although confusing phenomena is disappointing, the fact that 12-year-old pupils do not recognize a phenomenon is even more disappointing. Responses, according to which there is no change in the level of boiling water (Q1), water does not exist after evaporation (Q3), or alcohol cannot evaporate (Q5), indicates such pupils' misconceptions. Beyond these misconceptions, there is another problem with using water as 'the' example of the liquid state. This leads to the establishment of water as the 'prototype' substance for all liquid states (Krnel et al., 1998), which can explain pupils' thoughts that only water can evaporate, or pupils' ignorance about the nature of alcohol (e.g. '*alcohol contains chemicals*').

However, beyond the nature of pupils' misconceptions and their mental representations, the statistical analysis supported the hypothesis that these representations are associated with convergent and divergent thinking. The findings agree with other related research (Danili & Reid, 2006; Tsitsipis, Stamovlasis, & Papageorgiou, 2012), and strengthen the role of such variables in science learning, which seem to operate at the very beginning stages of pupils’ mental development. However, in order to avoid common reductionist flaws made in similar quantitative research, it is imperative to emphasize an epistemological remark. What is learned from probabilistic models applied to cross-sectional research data (e.g., Rasch, 1980; Tsitsipis et al., 2012) is that the above cognitive variables do play a role and somehow they are involved in the mental processes~~,~~ when children think or learn about the phenomena in question. No other information can be obtained; from a theoretical point of view these variables should be seen as constructs operationalizing certain mental recourses~~,~~ which are activated accordingly. The probabilistic association of these cognitive variables with mental representations confirms a connection between the activated mental resources and features (convergence/divergence) of the mental process required. That is, thinking about changes of state of substances requires a mind with divergent properties that can generate multiple representations and meanings, and on the other hand, also requires a mind with convergent properties that can focus and converge on a specific answer or on the unique solution.

The knowledge arising from the present findings is an important asset for teachers and scientists involved in science education who have to be aware of possible limitations in learning outcomes that could be due to a number of mental representations that average 12-year-old pupils have, but more significantly, might be due to limitations imposed by convergent and divergent thinking.

Divergent thinking is connected to linguistic abilities (e.g., Guastello, Bzdawaka, Guastello, & Rieke, 1992; Hudson, 1968; Bahar, 1999) and thus the role of language is a determining factor in learning and understanding changes in the state of matter. Deficiencies in linguistic abilities could be an obstacle for children in acquiring proper representations and, if so, from a pedagogical point of view the authors would propose that the determining role of language be circumvented as far as possible (Guastello et al., 1992; Orton, 1992). Illustrations and diagrams could clarify how the particulate structures of substances are associated with particular conditions related to external addition of energy, whereas software simulations could demonstrate the transition from one state to another when this energy changes. In any case, as these subjects are taught in a manner emphasizing aspects that result in rational explanations, one could facilitate understanding which might be hindered by the specific limitations of converging thinking.

In relation to the mental representations which are held by the majority of pupils, it is important for education to aim to create the concept of a substance through an appropriate design of a science curriculum together with teaching practices that emphasize substances’ properties and their transformations. As far as the science curriculum is concerned, the pupils’ understanding of the particulate nature of the substances is probably the key. As Johnson and Papageorgiou, (2010) suggested, a scheme including a progressive introduction of the particle theory in a simplified form in the beginning (involving only physical phenomena) and in a more advanced one later on (involving kinds of particles, bonds and chemical changes) could give pupils the opportunities to understand this paramount concept. To this end, teaching involving relevant representations of the submicro-world in connection to further explorations of phenomena in the real world could significantly help. In these explorations, examples and situations involving a range of substances (apart from water) would additionally have positive results.

Finally, it is important to state here that research on individual differences does not view the corresponding mental resources as predetermining students' academic development, but as mutually affected and coevolving with it, within the social and the educational environment (Stamovlasis & Papageorgiou, 2012). Moreover, the present thesis supports and encourages intervention programs and teaching methods that facilitate development through Science Education (e.g. CASE, Adey & Shayer, 1994).

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