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Optimising the use of note-taking as an external cognitive aid for increasing learning

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Abstract

Taking notes is of uttermost importance in academic and commercial use and success. Different techniques for note-taking utilise different cognitive processes and strategies. This experimental study examined ways to enhance cognitive performance via different note-taking techniques. By comparing performances of traditional, linear style note-taking with alternative non-linear technique, we aimed to examine the efficiency and importance of different ways of taking notes. Twenty-six volunteer adult learners from an information management course participated in this study. Cognitive performance scores from a traditional linear note-taking group were compared with another group by using a commercially available non-linear note-taking technique. Both groups were tested in two settings: after a classroom lecture and a panel forum discussion. Tasks included measures on story comprehension, memory, complexity of mental representations and metacognitive skills. Data analysis revealed that the non-linear note-takers were significantly better than the linear group both in terms of the quantity and the quality of the learned material. This study demonstrates the importance of using cognitively compatible note-taking techniques. It identifies the cognitive mechanisms behind effective note-taking and knowledge representation. Using such techniques enables deeper understanding and more integrated knowledge management.

Background

Note taking is one of the first and most established cognitive technology (Dror, 2007). As such, it offloads cognitive processes and extends our 'in head' cognitive abilities (Dror & Harnad, 2008). A great controversy in academic performance is that although students rely vastly on their information acquisition and representational skills (Armbruster, 2000), their note-taking efficiency is only around 20–40% in a typical lecture situation (Kiewra, 1985). In fact, a study found that the level of details in lecture notes accounted for half of the variance in students' final test scores (Titsworth & Kiewra, 1998). Therefore, much of learning is dependent on utilising appropriate strategies during knowledge acquisition.

From a cognitive psychology point of view, note-taking is a central aspect of a complex human behaviour related to information management that involves a range of underlying mental processes and their interactions with other cognitive functions (Piolat, Olive & Kellogg, 2005). Note-takers not only need to comprehend and write down personally flavoured information but, before that, they also need to acquire and filter the incoming sources, organise and restructure existing knowledge structures and, most importantly, they must store and integrate the freshly processed material. Therefore, the aim of a cognitive analysis of note-taking is to describe these mental processes, knowledge representations and memory functions.

Note-taking depends largely on the 'working memory' (WM; Baddeley, 2007). When taking notes of a presentation, we maintain a short-term memory buffer in order to acquire, mentally represent, select and understand the continuous flow of incoming new information and to update and interact with the already-stored knowledge (Piolat *et al*, 2005). WM during note-taking contributes to processes such as cognitive load (Yeung, Jin & Sweller, 1997), comprehension (Daneman & Merikle, 1996) or writing (Levy & Ransdell, 2002). However, note-taking is constrained by the same capacity limits as WM. Katayama and Robinson (2000) argued that the primary obstacle of good-quality notes is the amount of cognitive overload experienced by the students.

On the level of the individual note-taker, the metacognitive knowledge is often reported as a key factor in academic performance (Hacker, Dunlosky & Graesser, 1998). Metacognition is the knowledge about knowledge that is truly a critical skill from the very beginning of our literate existence that reflects on the highest level of cognitive functioning in which the human note-takers need to be reflective and aware of their own abilities of recording information in writing. The complexity of the cognitive operations and the knowledge involved in a process such as note-taking require note-takers to actively control what they are doing and to master the way they work. This metacognitive knowledge allows them to plan their activity, to evaluate and regulate it (Rémond, 2003). Garcia-Mila and Andersen (2007) further argued that metacognition is important for at least two reasons. First, as learners often misperceive the task demands and their own future state of knowledge, they do not see the utility of note-taking. Second, these misperceptions make learners not refer back to their notes and thereby miss feedback that would refine their metacognitive knowledge and strategy use.

Non-linear note-taking techniques

Piolat *et al* (2005) argued that the most fundamental reason behind the development of different note-taking styles and techniques is severe time pressure. In laboratory experiments, researchers measured the average rate of speech as being 2–3 words per second, while the average handwriting speed as only around 0.2–0.3 words per second. These figures demonstrate the need and relevance of a good temporal information

Table 1: List of non-linear note-taking techniques

Name of the technique	*Reference(s)*
Clustering	Rico (1983)
Concept mapping	Canas *et al* (2003); Novak and Gowin (1984)
Cornell system	Pauk (2001)
Idea mapping	Nast (2006)
Instant replays	Turley (1989)
Ishikawa diagram	Ishikawa (1984)
Knowledge maps	O'Donnell, Dansereau and Hall (2002)
Learning maps	Rose and Nicholl (1997)
Mind mapping	Buzan (2000); Catchpole and Garland (1996); Gruneberg and Mathieson (1997); Hartley (2002); Mento, Martinelli and Jones (1999)
Model maps	Caviglioli and Harris (2000)
Pyramid principle	Minto (1987)
Semantic networks	Lehmann (1992); Sowa (1991)
SmartWisdom	Kemp (2006)

management technique. The problem is exacerbated when one considers that the note-takers need to learn. In contrast to court reports and other special situations where shorthand typists need to record verbatim the spoken words, note-takers in general are there to learn the semantic meaning. Thus, note-taking is not an objective by its own right but a tool and an aid for learning.

Previous studies revealed mixed overall results of non-linear note-taking strategies (see Table 1 for an overview of such strategies) with regard to their benefits in learning outcomes compared with linear recordings (Boyle & Weishaar, 2001; Hartley, 2002). For example, when participants in a study were directed to use particular styles of notes (outlining, matrix or traditional), Kiewra *et al* (1991) found no difference between the groups in memory tests either immediately after learning or after a short review period.

However, the majority of the researchers agree that graphs and concept maps can be useful in selecting, encoding and organising information that leads to better remembering of the study materials (Robinson, Katayama, DuBois & DeVaney, 1998; Samarawickrema & O'Reilly, 2003). There is supporting evidence that organised and well-structured notes positively correlate with test scores and overall learning benchmarks in students (Titsworth & Kiewra, 1998, 2004). Titsworth (2004) argued that organisational cues of lecture notes enhance academic performance because they can help students to reduce their cognitive loads by providing determined note structures. Nevertheless, the outcomes of taking notes in a non-linear format highly depend on the actual technique used and the competence in utilising it.

SmartWisdom: A non-linear example of note-taking

Several commercial and freely available non-linear note-taking approaches exist (see Table 1 for a list). An exhaustive overview of all these methods is beyond the scope

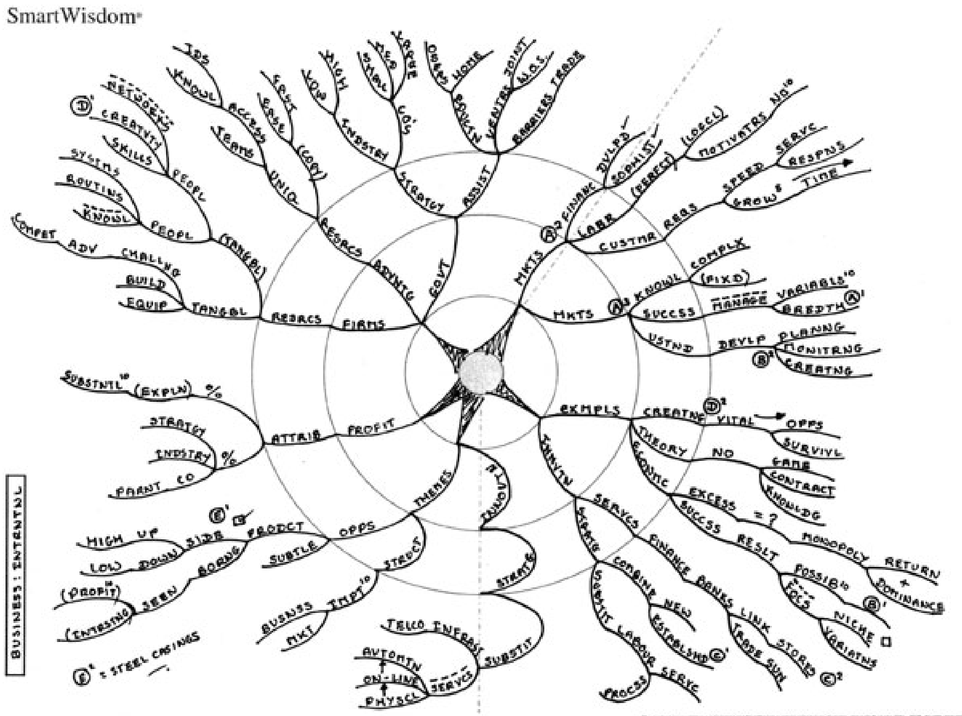
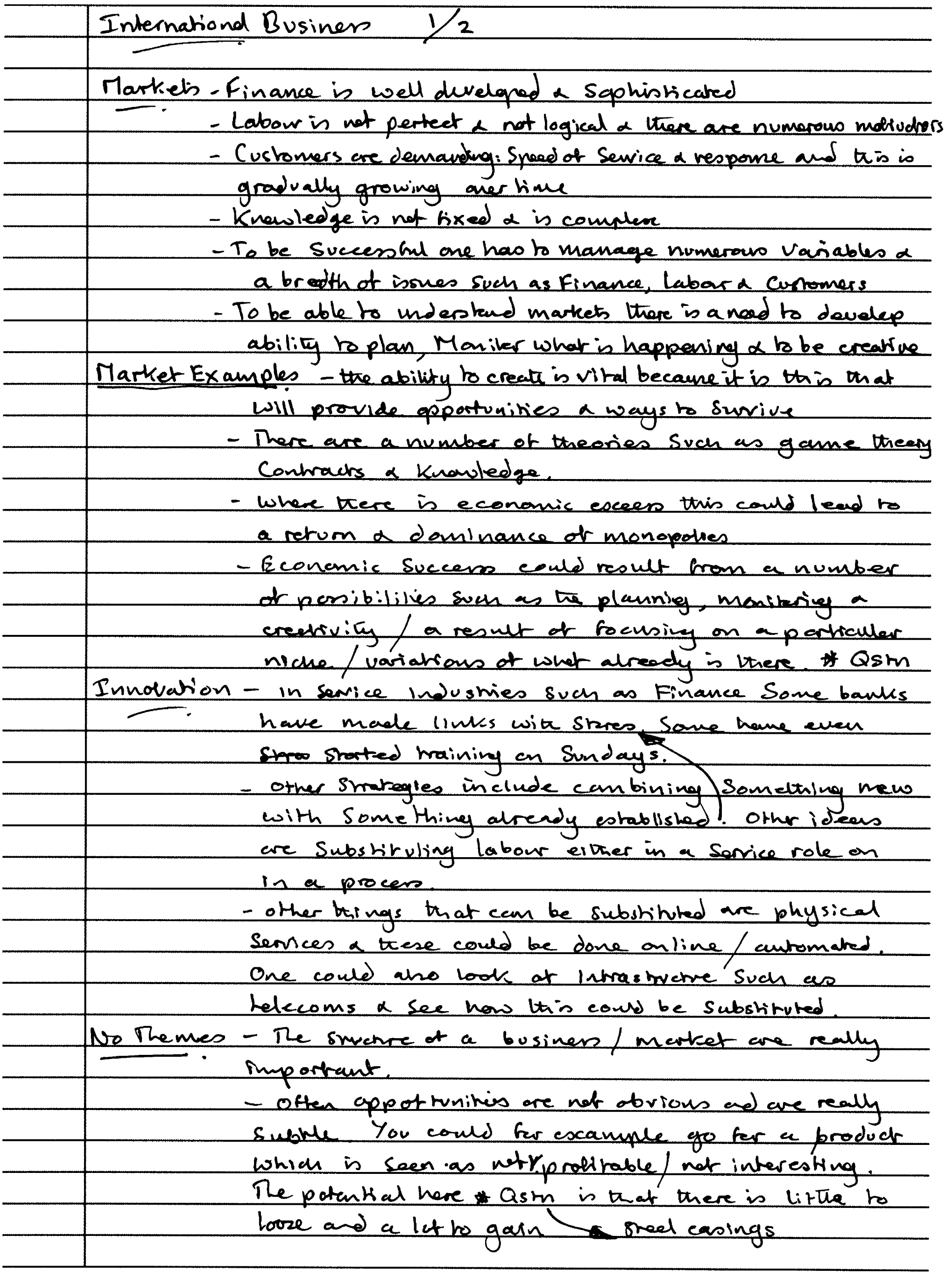


Figure 1: Example of a non-linear type note with SmartWisdom methodology

of this paper. For the purpose of this research, we selected one of the non-linear note-taking techniques—the SmartWisdom (Smart Wisdom Ltd, London, UK) approach—and compared it against traditional, linear note-takings (see Figures 1 and 2 for examples of the two types of notes). We had multiple rationales for using SmartWisdom as the non-linear technique in our study. First, it is a highly developed and broadly used note-taking method with hundreds of active users within the UK. Second, this technique shares the main characteristic features (see later in this section) with most non-linear techniques, which makes the findings in this study more applicable and valid. Finally, and beyond these theoretical justifications, on a more pragmatic level, we had access to SmartWisdom users, including before and after training, and those who have used this technique for a long time.

Information in the SmartWisdom technique is recorded in real-time and graphically represented in an organised, semi-hierarchical format (Figure 1). The blank SmartWisdom notebook sheets are used in a landscape orientation and feature four concentric circles in the middle of the page. These circles guide the note-taking process by providing a structured border to the first few levels of the recorded information. The SmartWisdom technique uses single words with capitalised letters as base units of the notes instead of full sentences. These base units are written over simple curved lines


International Business 1/2

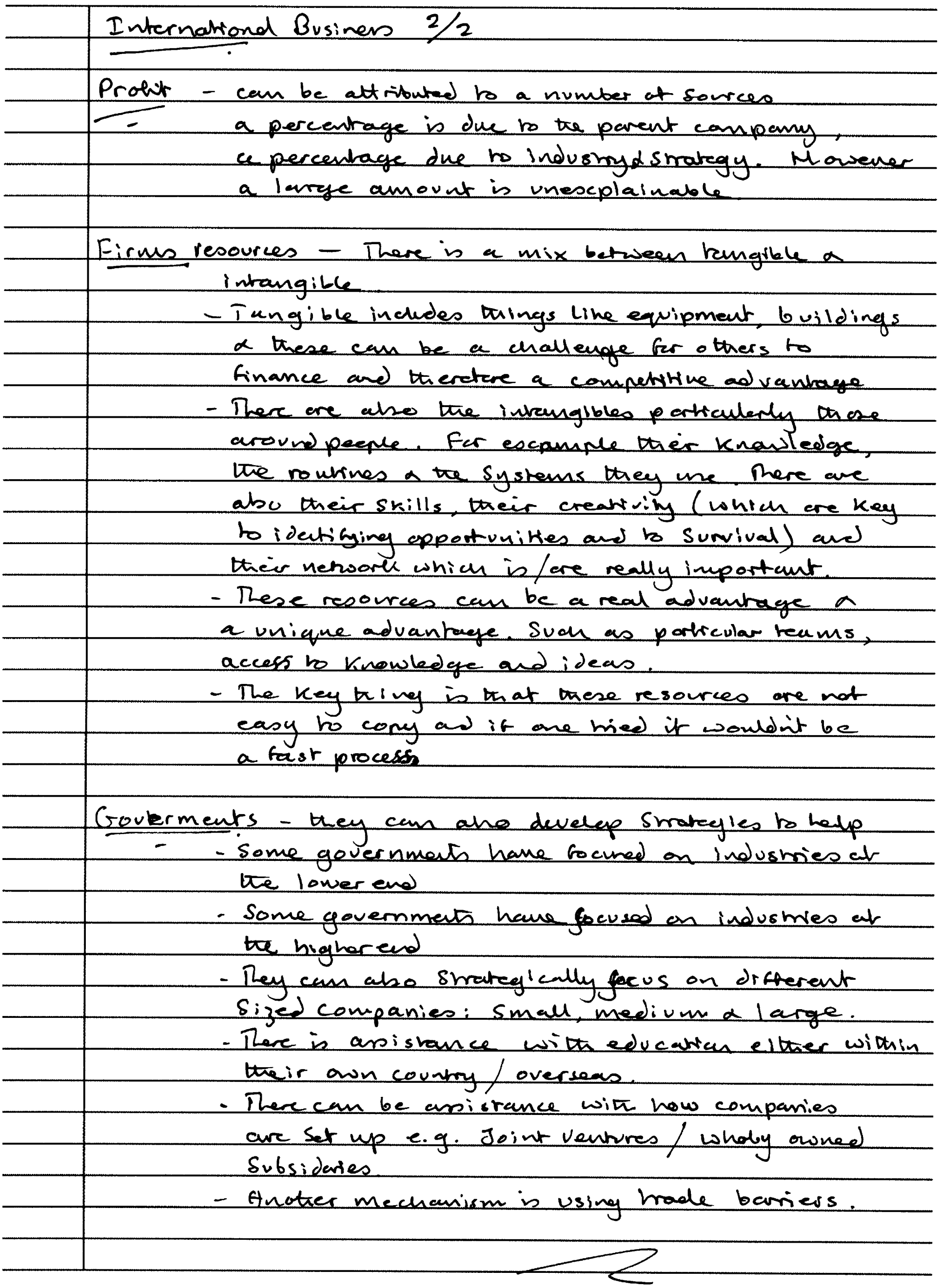
Markets - Finance is well developed & sophisticated
- Labour is not perfect & not logical & there are numerous motivators
- Customers are demanding: Speed of Service & response and this is gradually growing over time
- Knowledge is not fixed & is complex
- To be successful one has to manage numerous variables & a breadth of issues such as Finance, Labour & Customers
- To be able to understand markets there is a need to develop ability to plan, Monitor what is happening & to be creative

Market Examples - the ability to create is vital because it is this that will provide opportunities & ways to survive
- There are a number of theories such as game theory Contracts & Knowledge.
- Where there is economic success this could lead to a return & dominance of monopolies
- Economic Success could result from a number of possibilities such as the planning, monitoring & creativity / a result of focusing on a particular niche / variations of what already is there. # Qstn

Innovation - in Service industries such as Finance Some banks have made links with Stores. Some have even started training on Sundays.
- Other Strategies include combining something new with something already established. Other ideas are substituting labour either in a service role or in a process.
- other things that can be substituted are physical Services & these could be done online / automated. One could also look at Infrastructure such as telecoms & see how this could be substituted.

No Themes - The structure of a business / market are really important.
- Often opportunities are not obvious and are really subtle. You could for example go for a product which is seen as not profitable / not interesting. The potential here # Qstn is that there is little to loose and a lot to gain → steel casings

Figure 2: Example of a traditional linear note (2 pages)


International Business 2/2

Profit - can be attributed to a number of sources
- a percentage is due to the parent company,
a percentage due to industry & strategy. However
a large amount is unexplainable.

Firms resources — There is a mix between tangible &
intangible
- Tangible includes things like equipment, buildings
& these can be a challenge for others to
finance and therefore a competitive advantage
- There are also the intangibles particularly those
around people. For example their knowledge,
the routines & the systems they use. There are
also their skills, their creativity (which are key
to identifying opportunities and to survival) and
their network which is/are really important.
- These resources can be a real advantage &
a unique advantage. Such as particular teams,
access to knowledge and ideas.
- The key thing is that these resources are not
easy to copy and if one tried it wouldn't be
a fast process

Goverments - they can also develop strategies to help
- Some governments have focused on industries at
the lower end
- Some governments have focused on industries at
the higher end
- They can also strategically focus on different
sized companies: small, medium & large.
- There is assistance with education either within
their own country / overseas.
- There can be assistance with how companies
are set up e.g. Joint ventures / wholly owned
subsidaries.
- Another mechanism is using trade barriers.

Figure 2: Continued

(stems), and all stems can be traced back to one of the small triangles (spacers) drawn around the innermost circle. The stems can—but not necessarily have to—branch into a further series of three stems on all levels. The interconnected stems form an overall treelike structure that preserves the time structure of the presentation as all SmartWisdom notes go clockwise and start from the uppermost positioned and slightly right-hand tilted first spacer. Although, in most cases, the critical pieces of information are on the first few levels and more details are represented in the outer regions, the main emphasis is on the real-time flow of the recordings followed by the hierarchical structuring.

As with most non-linear techniques, SmartWisdom notes are on a single sheet. Hence, the whole of the recorded presentation can be overviewed with no interruptions of page turnings, providing a good holistic overview. The created SmartWisdom notes can be instantly used after—or even during—note-taking as they do not require further preparations or amendments. Important points, actions or future questions can be highlighted with different codes and colours, but, in general, the use of graphics or contrast marking is kept to a minimum. Reviewing SmartWisdom notes may focus on a particular part (ie, examining a series of stems or spacers), all the headings contained in one of the circles, or it may be holistic (ie, replaying the entire presentation). In either case, the review process goes along the flow of the recordings as the information is read out by following the clockwise-interconnected stems. Compared with traditional linear notes (Figure 2), where sentences follow a fixed sequence, the non-linear branching in SmartWisdom allows some variability in reading back and interpreting the recorded information; nevertheless, it promotes the use of the original expressions and terminology.

Objective of this study

In this paper we present a comparative study of two different note-taking techniques (traditional linear and non-linear SmartWisdom) based on cognitive measures that are essential for efficient and effective academic performance. Two groups of participants were tested in a between-participants design. Academic performance was measured in both groups and in two settings: after a classroom lecture and a panel forum discussion.

Our research questions were:

- Do learners with a typical non-linear note-taking technique perform better than traditional note-takers on tests of comprehension, accuracy and memory?
- What are the cognitive underpinnings of differences in learning efficiencies, if any, between linear and non linear note-takers?
- How would non-linear notes influence the cognitive structure of knowledge representations?
- What is the effect of different note-taking strategies on the learners' metacognitive skills?

The experimental tasks in our study measured comprehension, accuracy, complexity of knowledge representation, memory and metacognitive skills. Our study was aiming to identify optimal cognitive processing within those note-taking strategies that promote good academic performance. We hypothesised that participants with non-linear notes are cognitively more effective than the traditional linear group. This might be based on their better optimised information management system.

Method

Participants

Twenty-six adult learners participated voluntarily in this study ($n = 26$). They were taking part in an information management course. The average age of our participants was 38.43 years (standard deviation = 7.08) with the age range of 26–49 years. There were 14 female and 12 male participants in the study. All the participants had professional qualifications in finance or management domains.

The participants were allocated into two groups based on their previous experience with non-linear note-taking techniques: (1) non-linear (NL) group of note-takers, who have been experienced users of the SmartWisdom technique, and (2) control group with no experience with the SmartWisdom technique. Out of the 26 participants, there were 17 in the NL group and 9 controls. The participants in the NL group had an average experience of actively using non-linear note-takings for 2.61 years (standard deviation = 3.25). The controls were using traditional linear methods (eg, longhand recording, bullet points, etc.) to take notes.

Materials

Two video clips, 5 minutes long each, were used in the study. The first video was a public science lecture by a single lecturer. The topic was cryptozoology. the study of hidden animals. The second video clip was a formal conference panel discussion of the expected financial trends in the US for the year. It included five panellists, one of whom chaired the meeting.

The video clips were played from a laptop computer that was connected to a data projector, which showed a widescreen image on a white display panel. The audio output of the laptop was also connected to an integrated speaker system of the room, which produced a clearly audible voice throughout the videos.

Participants were given an evaluation booklet that contained general information, consent forms, empty sheets for note-taking and subsequent pages with the tasks that measured performance. An independent research assistant who was blind to the aims of the study scored the raw data. There were five tasks following each video presentation (see Table 2 for a summary of tasks).

Task 1: comprehension

In the first task, participants were asked to give a detailed summary of each presented video clip. The use of their notes was permitted. The scoring of this task was based on the comprehensiveness and preciseness of the answers. A maximum of 10 points was given if all main ideas were covered in the summary and there was no incorrect state-

Table 2: List of the tasks used in this study

Name	*Short description*	*Scoring*
1. Comprehension (☒, 👎)	Give detailed summary of the video clips	0–10 points. Maximum score if all main ideas are included and correct.
2. Accuracy (🕮, 👎)	Four short questions on main concepts of the video clips	0–8 points. 2 points for each complete and accurate answer. 1 point for each incomplete, but otherwise true answer.
3. Mental Imagery and Complexity (🕮)	Draw a diagram that includes all main concepts and how these are related to one another.	Nodes: number of individual concept on the diagram; Edges: connecting lines between nodes; Complexity index: $\sum \frac{\text{Number of edges}}{\text{Number of nodes}}$ (1)
4. Metacognition (🕮)	Two questions on how they rate their own note-taking	0–100% of self-ratings.
5. Memory (☒, 👎)	Two questions on Video 1 (cryptozoology) 4 hours after presentation.	0–4 points. 2 points for each complete and accurate answer. 1 point for each incomplete but otherwise true answer.

🕮 Use of notes was permitted.
☒ Use of notes was forbidden.
👎 Negative marking was applied (penalty score of 1 for every incorrect information).

ment. Negative marking was applied, so that any additional information that was not in the actual presentation was penalised and a score of 1 was deducted.

Task 2: accuracy

In the second task, four questions were asked in relation to each video presentation. Participants had to give accurate short answers, which were scored with a maximum of 2 points per question. Incomplete but not untrue answers received a score of 1 point. If any part of the answer contradicted with the presentation content, then a deduction of 1 point was applied. Participants were allowed to use their notes.

Task 3: mental imagery and complexity

In Task 3, participants were asked to draw a diagram for each presentation with the help of their notes. These diagrams aimed to map the structure of the participants' mental representations. Scoring these diagrams involved counting the total number of nodes (individual concepts written within the diagram, eg, 'taxation' or 'budget') and edges (connecting lines between nodes). A complexity index was also calculated by dividing the total number of edges by the total number of nodes (Rauterberg, 1992). This index describes how well concepts are integrated within a relational knowledge structure. A complex mental structure, where nodes are highly interlinked with many edges, involves a wide range of cognitive processes, including associations, anchoring, referencing and mental abstraction.

Task 4: metacognition

The last two questions, in which the participants were allowed to review their notes, required self-ratings of their own note-taking performance. The participants answered in terms of percentages of how well their note-taking covered the presentations.

Task 5: memory

In Task 5, the participants were asked to answer two questions, without their notes, in relation to the first presentation that they were shown earlier. Fully complete and correct answers were given 2 points, while incorrect responses were negatively marked.

Procedure

Participants of the NL group were tested in standardised individual sessions, whereas the controls were tested in one group setting. Regardless of the setting, each test session took 45 minutes to complete, and there was an additional 5-minute-long memory task 4 hours later. In the first part of the session, the participants were asked to watch and listen to the first video presentation (public science lecture by single lecturer). Simultaneously, the participants were asked to take notes according to their groups (ie, NL group with SmartWisdom technique; controls with traditional linear or longhand notes). After watching the presentation, they immediately and individually started answering the questions about the presentation. The participants were allowed to use their notes for Tasks 1–4 and were given 15 minutes to finish.

After a small break, the participants were prompted to pay attention to the screen once again and were presented with the second video presentation (conference meeting with multiple speakers). Similarly to the first part, they were asked to take their notes while watching the video clip. The presentation was followed by the second set of questions (Tasks 1–4). Same as before, the participants could use their notes for answering the questions and were once again given 15 minutes.

After a delay period of approximately 4 hours, the participants' memory of the first presentation was tested with Task 5. This time, participants could not use their notes and had to answer the questions from memory. Upon the completion of Task 5, the session was ended.

Results

Cognitive processes that are highly relevant for good academic performance were analysed separately for the lecture and the meeting video presentations (see Figures 3 and 4 respectively). NL note-takers significantly outperformed the linear control group on multiple measures. Means and Standard deviations of the raw scores are reported in Table 3. The alpha level for all reported significant results was $p < 0.05$ unless otherwise stated.

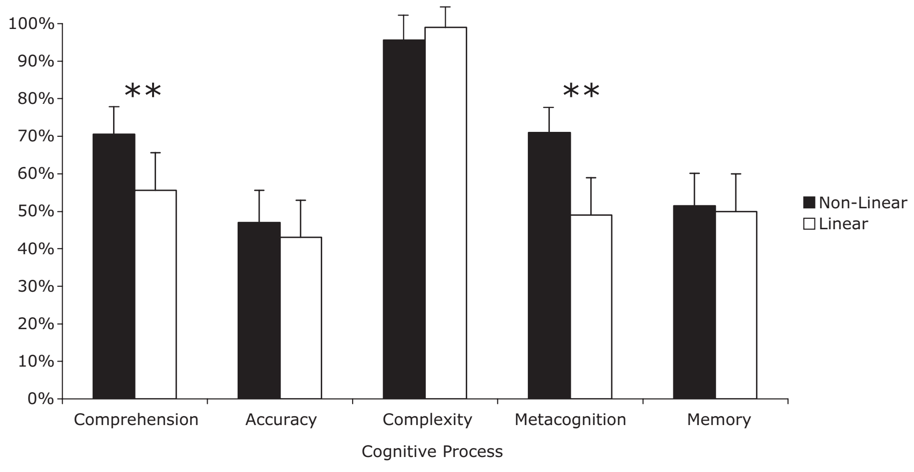


*Figure 3: Cognitive performance levels after the public science lecture with a single lecturer video presentation in the two note-taking groups (**p < 0.05)*

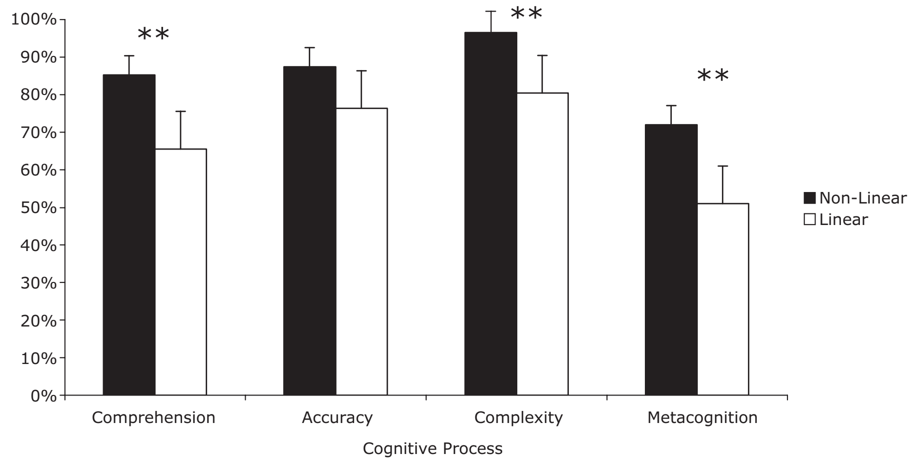


*Figure 4: Cognitive performance levels after the conference meeting discussion video presentation in the two note-taking groups (**p < 0.05)*

Comprehension (Task 1) scores were higher for the NL group compared with controls, $F(1, 25) = 5.79$ and $F(1, 25) = 6.84$ respectively, for the lecture and meeting presentations. NLs produced 15% more comprehensive and coherent stories after the lecture and 19% better such scores after the meeting presentation.

There was no difference in the Accuracy scores (Task 2) between the two groups. Although participants were more accurate in recalling specific details from the meeting presentation (in average 80% correct answers) than from the lecture (45%),

Table 3: Means and SD of the performance results in the experimental tasks for the two groups (non-linear and control) in the two video presentation situations (lecture and meeting)

		Lecture presentation				*Meeting presentation*			
		Non-linear group (n = 17)		*Control group* (n = 9)		*Non-linear group* (n = 17)		*Control group* (n = 9)	
Cognitive process	*Task*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Comprehension	1	7.06	1.60	5.56	1.33	8.53	1.46	6.56	2.40
Accuracy	2	3.76	2.46	3.44	1.13	7.00	1.17	6.11	1.83
Number of Nodes	3	13.59	6.69	12.89	8.19	15.06	6.23	12.11	4.91
Number of Links	3	13.00	6.23	12.89	8.43	14.76	6.58	10.44	5.64
Complexity	3	0.96	0.13	0.99	0.14	0.97	0.15	0.80	0.19
Metacognition	4	0.71	0.22	0.49	0.17	0.72	0.12	0.51	0.19
Memory	5	2.06	1.25	2.00	1.12	n/a	n/a	n/a	n/a

n/a, not applicable; SD, standard deviation.

$F(1, 24) = 28.10$, the note-taking style had no effect on either of these performances, $F(1, 24) = 1.50$, (not significant).

Comparisons of the mental imagery diagrams in Task 3 revealed that participants in both groups used the same number of nodes and edges in the two presentation situations. However, the comparison of the complexity ratios (edges/nodes) in the meeting presentation were significantly higher for the NL group than for controls, $F(1, 25) = 5.62$. This result demonstrates that NL note-takers optimised the represented information better than the control group by connecting each individual node with 17% more edges to one another. Nevertheless, this difference was not found in the lecture presentation.

Metacognitive self-ratings in Task 4 were significantly higher for NL note-takers than for controls, $F(1, 25) = 8.06$ and $F(1, 25) = 12.19$ (respectively for the lecture and for the meeting presentations). NLs estimated their own performance to be over 70% in both presentations, whereas controls' such ratings were around 50%. However, when these rates were compared with actual performances (based on scores in Task 1), the self-ratings were found accurate in both groups for the lecture, $t(16) = 0.18$, n.s. and $t(8) = 1.00$, n.s. (respectively for the NL and control groups). For the meeting presentation, participants consistently underestimated their actual performance regardless of their note-taking styles, $t(16) = 2.53$ and $t(8) = 4.40$ respectively.

Finally, the memory scores (Task 5) were compared and no significant difference was found between the two groups, $F(1, 25) = 0.01$, n.s. Note-taking styles did not affect memory recall performances as both NLs and linear controls were only able to answer around 50% of the questions without the use of their notes.

Discussion

Human performance and learning are dependent on a set of cognitive skills and technologies related to the acquiring, processing, comprehending and remembering information that is presented to learners during various forms of training. Individual learners demonstrate different levels of competence in such cognitive skills. Learning strategies are the various behavioural activities that learners employ during their academic training programmes to achieve better learning outcomes (Weinstein & Mayer, 1986). Although there are several plausible explanations regarding what is the best approach to improve academic performance (Schuman, Walsh, Olson & Etheridge, 1985), note-taking has been definitely identified as an important learning strategy (Kiewra, 1984).

This experimental study assessed cognitive skills and performances of linear and non-linear note-takers. As note-taking equally often happens outside a formal single lecturer situation, had we had tested our participants' recording ability not only in a public lecture with a single lecturer but also in a group-meeting situation with multiple sources of information. The results from these two typical note-taking situations provided a wider scope for our interpretations in the assessment of the two learning strategies.

We found that NL note-takers performed on average 20% better than the linear control group in tasks measuring comprehension and metacognitive skills in both situations. These skills are critical for learning and for good academic performance. Comprehension refers to the construction of meaning by recognising interrelationships within and between information, making inferences to prior knowledge and integrating new information into existing knowledge structures (McNamara, de Vega & O'Reilly, 2007). When our participants had to summarise the stories of the presentations using their notes in Task 1, they were actively practising their comprehension skills. Non-linear notes allowed the students to coherently include more details in their summaries. The single-word base units (nodes of information on each separate curved line) forced these note-takers to condense longer sentences into a semantically higher category level, hence pre-processing information already in the encoding phase. This initial cognitive effort paid off in the 20% increased comprehension performance.

NL note-takers were also more positive than the linear group about their own capabilities of recording information. In both presentation situations, they perceived themselves to be more positive and reported that they were able to note down and understand greater than 20% more information than the other participants. For a successful learning, metacognition (knowledge about knowledge) needs to be realistic and to follow the dynamic changes of the actual performance. The increase of metacognitive awareness could reflect on an active development of the learning strategy, only if it corresponds to a similar growth in the actual performance (Hacker *et al*, 1998). However, we found mixed results when self-assessed and actual performances were compared within our participants. Both non-linears and controls were accurate about their notes in the lecture presentation and underestimating them in the meeting presentation. Thus, we found no evidence that non-linear style would increase the correctness of self-assessment any better than linear style notes. The situation of the presentations was more important and suggesting that participants are generally more familiar with recording notes from a lecture with a single presenter than from a meeting with multiple sources of information.

Although the Accuracy scores were slightly higher for the non-linear group than for the controls, statistically significant difference was not reached. This suggests that note-taking style has no real effect on how precisely the learners are going to use their notes. On the other hand, it is also indicated that other factors, such as metacognition, play a significant role. As the non-linear technique allowed its users to record 20% more comprehensive information compared with linear controls, the fact that there is still no difference in accuracy despite the increased information-processing demand suggests that the performance gains of non-linear learners have no measurable qualitative drawbacks.

On a structural level, the benefit of the non-linear note-takings is that the technique offers a visually accessible format that takes off cognitive load from the learner, hence making the process of note-taking more effective (for a similar structural analysis, see Makany *et al*, 2007). The branches (connector links between nodes of information) in a non-linear note are very apparent and make semantic links more explicit than in traditional linear notes. Often, the most important pieces of information are closer to the centre of the page, while details are on the periphery. As the starting position is always associated to the upper right-hand corner of the page and the direction of recording is clockwise, the sequence of the base units guides both the encoding and the review processes. Consequently, non-linear note-taking is cognitively less demanding and allows the note-taker to focus on the learning material instead on how to organise the notes.

Non-linears also outperformed the linear control group in their representational complexity ratios in the meeting presentation situation. The mental imagery diagrams revealed that non-linears achieved better performance results not by recording significantly more details of the presentation but instead by putting concepts and examples into a semantically more connected network of mental representations. This suggests that non-linear note-taking has a cognitively more optimal knowledge management system than traditional note-taking. It allows the non-linear users to integrate the newly acquired pieces of information better into their existing network of mental representations. The lack of similar results in the single lecturer situation, however, points out that non-linear note-taking is more useful if there are not one but multiple sources of information to be recorded. Further research is needed to determine the different cognitive mechanisms behind this difference.

Similar to Kiewra *et al*'s (1991), this study also found that the higher overall information management performances of NL note-takers did not originate from their prominent short-term memory skills. Our participants in either group answered correctly around half of the questions, in which they were not allowed to use their notes. This suggests that the excellence of NL note-takers in other measures of academic performance is a result of their advanced information management technique that allowed better access and utilisation to recorded data. This finding also rules out a potential interpretation that non-linear participants might have performed better than controls because of their individually more advanced WM abilities.

Nevertheless, a possible limitation to this study is topic familiarity and difficulty based on the arbitrary choices of both video presentations. It could be that the single-lecturer presentation was too unfamiliar and difficult topic (ie, criptozoology) for the participants to take notes in contrast to the meeting video with the US financial trend analyses. Other studies should systematically control these factors of the stimuli to eliminate potential presentational biases.

In summary, this study assessed the underlying cognitive mechanisms behind effective note-taking and knowledge representation. We presented the advantages and the drawbacks of a non-linear note-taking learning strategy, which seemed to overall increase academic performance through deeper understanding and highly integrated knowledge management. Participants with such learning strategy represented information in a semantically more connected and meaningful way than their peers with traditional, linear note-taking strategy. Our study and findings illustrate the importance of examining learning tools and technologies from a cognitive perspective (Dror, 2007, 2008).

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