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THE THINKING STYLES OF UNIVERSITY MATHEMATICS STUDENTS

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Abstract: In this paper, we focus on the relationship between studying university mathematics and the 'thinking styles' of both undergraduate and postgraduate mathematics students. A cross-sectional quantitative study (*N* = 238) was conducted in a large Greek university, identifying the thinking styles of second, third and fourth year undergraduates, as well as those of students following a postgraduate degree in mathematics. The analysis revealed that the more experienced undergraduates and the postgraduates showed a stronger preference for originality and freedom in thinking, low degrees of structure, high levels of freedom and more complex information processing, combined with non-prioritised thinking. However, the postgraduates combine these preferences with a stronger preference for implementing rules and instructions. A discussion on these findings and on the factors that may account for them is presented.

Key words: university mathematics, thinking styles, undergraduates, postgraduates, MSC 97C30

1. Thinking and mathematical thinking

In the general educational and psychological research, various researchers argue for the existence of general cognitive preferences, usually described by the construct of *cognitive style*, which can be defined as "an individual's characteristic and consistent approach to organizing and processing information" (Tennant, 1988, p. 89). Little research has been conducted into the interaction between these cognitive styles and studying mathematics and/or advanced mathematics (Duffin & Simpson, 2002; Pitta-Pantazi & Christou, 2009).

Although there appear to be variations in the conceptualisation of cognitive styles, most theorists agree that cognitive style is relatively stable over time and context (Zhang & Sternberg, 2001). Therefore, by focussing on students' thinking styles, we essentially look for the medium-to-long term interactions between university education and the student's way of thinking and for relatively stable thinking characteristics that the undergraduates and the postgraduates may share. Such a study will help us in finding out more about the outcomes of the existing university educational system on the thinking of the students who form the 'pool' from which future mathematics teachers and mathematicians derive. This is crucial both for the mathematical community and for the general community as the majority of future mathematics teachers will be amongst these graduates.

In a previous study (Moutsios-Rentzos & Simpson, 2005) we focussed on the transition from university mathematics to a taught postgraduate degree in mathematics. In that study, we highlighted two apparently conflicting conjectures. The first conjecture was that the existing undergraduate educational system, with the rapid delivery of new material, might favour students who have a preference for absorbing new information without any particular short-term search for links with existing knowledge (Duffin & Simpson, 2002) and so postgraduates, having been successful in that environment, would maintain most of those thinking styles. The second conjecture, suggests that the students who choose to follow a postgraduate degree are distinct in their approaches to study from the general graduate population and, therefore, the postgraduates "become increasingly surface and decreasingly deep in their orientation to learning" (Biggs, 2001 p. 91).

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In this paper, we further consider this apparent conflict. We adopt one conceptualisation of the general construct of cognitive style, Sternberg's (1999) *thinking style* (the "preferred way of using the ability one has", p. 8) to identify the links, if any, between studying university mathematics and the students' general thinking preferences. In particular we ask the following research question:

What are the differences and similarities in thinking style between undergraduate mathematics students that are in different year groups and how do they compare with the students on a postgraduate degree in mathematics?

2. Theoretical framework

2.1. Cognitive consistencies in thinking and in mathematical thinking

The tension between the individuals' thinking in specific situations and their general preferences for thinking has been the topic of a long debate in education and psychology. Entwistle, McCune and Walker (2001) note that the "apparent conflict between descriptions of stable individual characteristics and the evidence of specific reactions to tasks is well recognized" (p. 114) and that there can be "identified both stable and less stable patterns in students' reactions to tasks and contexts" (*ibid*).

In this paper, we focus on relatively stable patterns in the students' thinking by adopting Sternberg's conceptualisation of thinking style. This decision is in line with evidence suggesting that students do have some kind of preferences when thinking about mathematics: from amongst mathematicians (Mac Lane, 1994) and graduate research students (Duffin & Simpson, 2006) to elementary school students (Gray & Pitta-Pantazi, 2006). Furthermore, the mathematical thinking preferences identified by mathematics educators appear to share characteristics with more general, psychological or educational, research.

Burton (2001), in her work with research mathematicians, identified three styles of thinking about mathematics from a representational perspective: "Style A: Visual (or thinking in pictures, often dynamic); Style B: Analytic (or thinking symbolically, formalistically); and Style C: Conceptual (thinking in ideas, classifying)" (p. 593). Borromeo Ferri and Kaiser (2003) partially reconstructed these styles in the mathematical thinking of students being 15-16 years old. In the context of students' information processing, Duffin and Simpson (2006) suggested four types of mathematical learners: *alien* (preference for absorbing new information without trying to link it with the existing knowledge), *natural* (preference for integrating new and old knowledge in a coherent 'global' structure), *coherence* (preference for finding a 'local' structure in the new knowledge) and *flexible* (preference for adopting different ways of thinking depending on the situation). Both of these models fit nicely with the two cognitive style dimensions that Rayner and Riding (1997) identified: a) verbal vs. image-based, and b) wholistic vs. analytic. The first dimension is associated with the preferred *mode of the information representation*, whilst the second is related to the preferred *mode of information processing*.

Consequently, we argue that the construct of cognitive style can be conceptually related to existing mathematics education research findings about consistencies in the students' thinking about mathematics and, thus, may be useful to further our understanding.

2.2. Thinking styles and the Theory of Mental Self-Government

Sternberg clearly defined the notion of 'thinking styles' in terms of their derivation from an underlying theory of cognitive organisation: the *Theory of Mental Self-Government (MSG)*. MSG is based on a metaphor between the way that the individuals organise their thinking and the way that society is governed (Sternberg, 1999). Thirteen thinking styles are identified and organised in five dimensions: *function*, *forms*, *levels*, *leanings* and *scope* of mental self-government (see Table 1). Zhang and Sternberg (2006, 2009), after considering conceptual and empirical evidence, identified three *types* of thinking styles: a) *Type I* (preferences for originality and freedom in thinking, low degrees of structure, high levels of freedom and more complex information processing), b) *Type II* (preferences for conformity, structured tasks, authority and straightforward information processing), and c) *Type III* (styles that can be linked with characteristics of either Type I or Type II styles, "depending on the stylistic demands of a specific task"; p. 115).

By adopting Sternberg's conceptualisation, we focus on the students' general thinking preferences from the perspective of the mode of information *processing* (rather than 'representation').

Table 1. Dimensions of thinking styles and sample items from TSI (Sternberg, 1999).

Dimensions	**Thinking Styles** (description; sample items from TSI)
Functions	**Legislative** (preference for creativity; "I like problems, where I can try my own way of solving them") **Executive** (preference for implementing rules and instructions; "I like projects that have a clear structure and a set plan and goal") **Judicial** (preference for judging; "I like to check and rate opposing points of view or conflicting ideas")
Forms	**Monarchic** (preference for focussing on only one goal; "I like to concentrate on one task at a time") **Hierarchic** (preference for having multiple prioritized objectives; "I like to set priorities for the things I need to do before I start doing them") **Oligarchic** (preference for having multiple equally important targets; "Usually when I have many things to do, I split my time and attention equally among them") **Anarchic** (preference for flexibility; "When there are many important things to do, I try to do as many as I can in whatever time I have")
Levels	**Global** (preference for the general and the abstract; "I tend to emphasise the general aspect of issues or the overall effect of a project") **Local** (preference for details and the concrete; "I pay more attention to the parts of a task than its overall effect or significance")
Leanings	**Liberal** (preference for novelty and originality; "I enjoy working on projects that allow me to try novel ways of doing things") **Conservative** (preference for conformity; "I like to do things in ways that have been used in the past")
Scope	**Internal** (preference for working alone; "When faced with a problem, I like to work it out by myself") **External** (preference for working in a group; "I like to participate in activities where I can interact with others as part of a team")

3. Methods

3.1. Sample and procedures

This study was conducted with 238 mathematics students in a large Greek university (see Table 2). It should be noted that there are clear differences in the nature of the undergraduate and postgraduate populations in respect of their volition: the Greek educational system produces a large number of students beginning a 4-year BSc mathematics degree without this being either their first or second choice, while the postgraduate students, in particular, have clearly chosen postgraduate study in the subject over other subjects or graduate routes. Our sample focussed on undergraduates with some level of university experience (thus, years 2 and above) and postgraduates in the first semester of their two-year MSc (who therefore do not have such an overwhelming postgraduate experience, but instead can be considered as a subpopulation of successful students who have chosen the postgraduate route).

For each student we obtained data about their attainment (in terms of total number of courses passed and grades achieved) and we asked them to complete a version of the 'TSI' - the Sternberg-Wagner Thinking Styles Inventory (Sternberg & Wagner, 1991). This is a self-report, paper-and-pencil test consisting of 104 items (8 for each of the 13 thinking styles described above). Because the data was collected at different times, they did not complete identical versions of the TSI – in particular, the postgraduate version omitted the 'scope' dimension and thus this played no role in our analysis.

In order to identify the students' thinking styles, their 'raw score' for each scale is computed and, subsequently, the raw scores for each style are compared against the norms provided, in order to determine the participants' style preference. The Sternberg norms vary according to the participants' gender and educational level and thus a participant's preference for a style can be: 'Very High' (Top 1%-10%), 'High' (Top 11%-25%), 'High Middle' (Top 26%-50%), 'Low Middle' (Top 51%-75%), 'Low' (Top 76%-90%), 'Very Low' (Top 91%-100%) (Sternberg, 1999). For example, if a female college student has a raw score of '5.3' in the legislative style, then this would put her in the Top 26%-50% and, consequently, would identify her 'High Middle' preference for this style.

Table 2. The participants of the study.

	Undergraduates (year group)			***Postgraduates***	
	2nd	**3rd**	**4th**	**MSc**	**Total**
Male	45	38	21	15	119
Female	54	32	21	12	119
Total	99	70	42	27	238

3.2. Identifying the students' thinking styles

Though the TSI has had its validity and its reliability verified across various studies and countries (Zhang & Sternberg, 2001), the absence of research implementing this instrument in a Greek university population urged caution in its implementation. Therefore, to administer TSI in this study, it was first independently translated and back translated from English to Greek and subsequently it was piloted to refine the language of the items. Moreover, TSI, is a norm referenced test and this is particularly important since it appears there is no published norm for Greek university students. Hence, following Moutsios-Rentzos and Simpson (2005), we decided that the participants' scores would be labelled both according to Sternberg's norm ('Sternberg's labels') and according to a norm ('adjusted labels') produced by the data of this population following Sternberg's process. The latter norm serves as a 'tighter lens', which helps in focussing on our population and spotting intra-population differences. The data analysis of our previous study showed the usefulness of this lens (by spotting a difference in the 'local' thinking style that the wider lens failed to identify) and, thus, it was also used for this study. Following these, for this paper, the analysis is mainly based on the adjusted norm, provided that the results did not contradict the results deriving from the Sternberg's norm.

4. Results

4.1. A note about the translated to Greek TSI

The translated to Greek TSI demonstrated good cross-cultural validity and reliability, as shown by its internal consistency, construct validity and by comparison against theory and previous studies. In sum, the translated to Greek TSI shows good internal consistency for 8 of the 13 measured style scales, while three of its scales are less reliable than desired, which, still, is in accordance with studies using translations from the original English version of TSI (Zhang & Sternberg, 2001). The computed correlations were, in general, as predicted by the theory of Mental Self-Government and previous research projects (Zhang & Sternberg, 2006). For example, 'conservative' and 'liberal' were negatively correlated (r_s= -.355, $p < .001$). Moreover, principal axis factoring (oblimin with Kaiser normalisation) led to a 3-factor solution (accounting for the 66.7% of variance). The first factor is related to creative, original, critical and non-prioritised thinking, the second factor is linked to procedural, already tested and prioritised thinking and the third factor embodies the 'scope' dimension of MSG ('internal'-'external'). This solution, in general, is in accordance with the Type I, Type II and Type III thinking styles respectively (Zhang & Sternberg, 2006; see §2.2.). Nevertheless, we wish to stress one difference: in our study, 'hierarchic' was assigned to the factor that included Type II thinking styles, while Zhang & Sternberg (2006) considered 'hierarchic' to be a Type I thinking style. We argue that, our population conceptually linked 'prioritised thinking' with 'procedural' and 'already tested' thinking (both reflecting Type II thinking preferences), which is justified by the fact that both 'hierarchic' and 'monarchic' were assigned to the factor containing Type II thinking styles. Accordingly, 'non-prioritised' thinking ('anarchic' and 'oligarchic') had loadings on the 'Type I' factor. Finally, the reported results are based on the adjusted norms, since no contradictions were found when comparing these results against Sternberg's norms.

4.2. The students' thinking styles

In order to identify the stylistic differences between undergraduates and postgraduates, as well as those amongst the different undergraduate year groups, we conducted several analyses the results of which are schematically outlined in Figure 1. First, we used the Mann-Whitney test, in order to compare the thinking styles of the undergraduates as a whole with those of the postgraduates. The undergraduates were found to be significantly less 'legislative' ($U = 1842$, $p < .01$, $r = -.20$), less 'executive' ($U = 1959.5$, $p < .01$, $r = -.17$), less 'oligarchic' ($U = 1402.5$, $p < .001$, $r = -.28$), but significantly more 'monarchic' ($U = 2167$, $p < .05$, $r = .17$), more 'hierarchic' ($U = 1194$, $p < .001$, $r = -.32$), more 'anarchic' ($U = 2163$, $p < .05$, $r = -.18$) and more 'conservative' ($U = 2163$, $p < .05$, $r = -.13$) than the postgraduates. These results provide us with an overview of the main stylistic differences between the two populations. The postgraduates appear to have a stronger preference for dealing with multiple, equally important tasks simultaneously ('oligarchic') and they seem to accommodate this preference with more creative ('legislative') and original ('liberal') thinking, as well as a preference for implementing rules and instructions ('executive). Thus it can be argued that the undergraduates seem to have a stronger preference for prioritized thinking and for conformity.

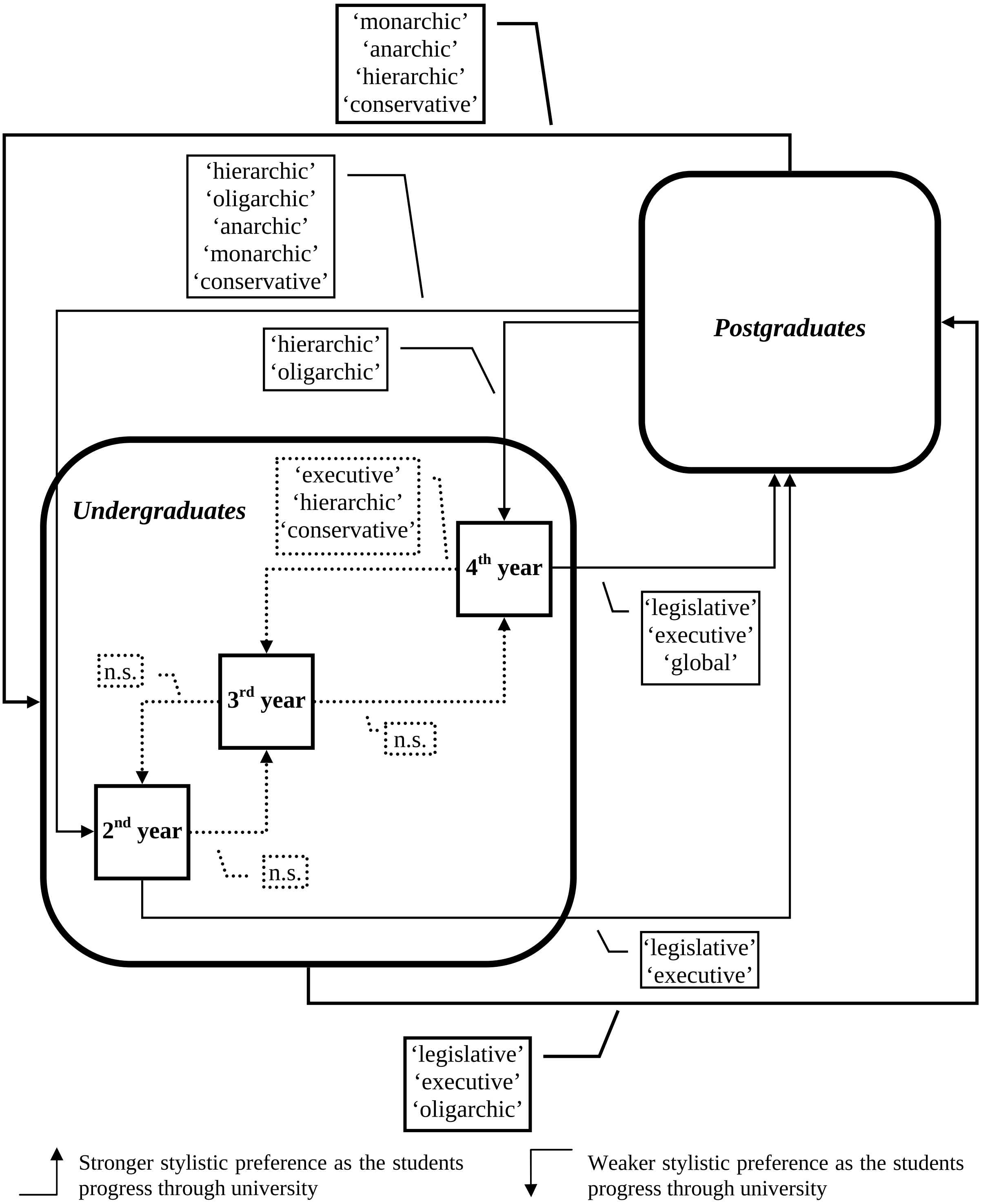
However, the undergraduates included in this study belonged to different year groups and, thus, they have a different level of university mathematics experience. On the one hand, the more university experienced students are expected to have studied more university mathematics, in the sense of the actual corpus of mathematical knowledge. On the other hand, the mere fact that these students have been university students longer may also have allowed them to develop a sense of belonging in a mathematical community, thus affecting their identity. It follows, that it is reasonable to assume that there may be some kind of stylistic development as the undergraduates progress through university.

Since the undergraduate sample consisted of three year groups, we conducted the Kruskal-Wallis test for all the measured thinking styles in order to detect any statistically significant changes as the students progress through undergraduate study. Four significant changes were found: the more university experienced the students are the less 'executive' ($H(2) = 10.683$, $p < .01$), less 'hierarchic' ($H(2) = 9.353$, $p < .01$), less 'global' ($H(2) = 8.591$, $p < .05$) and less 'conservative' ($H(2) = 11.125$, $p < .01$) they are. These findings fit with the stylistic differences between the undergraduates and the postgraduates; the more experienced students seem to develop stylistic characteristics similar to the postgraduates concerning the less 'hierarchic' and the less 'conservative' aspect.

However, there are also clear differences: in particular, the more experienced students appear to have a stronger preference for less 'executive' thinking, which contrasts the postgraduates' stronger preference for this type of thinking.

We conducted Mann-Whitney tests, with Bonferroni corrections, to follow up these findings: a) the 2nd year students against the 3rd year students, and b) the 3rd year students against the 4th year ones. The 2nd year students were found *not* to be significantly different from the 3rd year students in any of the thinking styles dimensions. Furthermore, the 4th years were found to be less 'executive' ($U = 954.5$, $p < .01$, $r = -.30$), less 'hierarchic' ($U = 1088$, $p < .05$, $r = -.22$) and less 'conservative' ($U = 972$, $p < .01$, $r = -.29$) than the 3rd years. Hence, it appears that the thinking styles profiles of the students who have just completed the first two years in university are not significantly different. On the other hand, there seem to be significant changes in the students' thinking styles profile as they enter the fourth year of the degree.

In order to delineate these findings, we chose to focus on the year groups that are further apart in our sample. The rationale of this choice was that the largest difference in the students' university experience might amplify the stylistic contrast. Thus, we used the Mann-Whitney test to compare the thinking styles profiles of the 2nd year and the 4th year undergraduates with the thinking styles profiles of the postgraduates. First, we found that the 2nd year students were found to have weaker preference than the postgraduates for 'legislative' (U = 919.5, p < .05, r = -.23) and 'executive' (U = 902.5, p < .01, r = -.24), as well as a stronger preference for 'hierarchic'(U = 503, p < .001, r = -.45), 'oligarchic'(U = 699.5, p < .001, r = -.34), 'anarchic' (U = 997.5, p < .05, r = -.18), 'monarchic' (U = 942, p < .05, r = -.21) and 'conservative' (U = 963.5, p < .05, r = -.30).



'solid' elbow arrow connectors: undergraduate-postgraduate stylistic comparison
'dotted' elbow arrow connectors: intra-undergraduate stylistic comparison
'n.s.': not statistically significant differences in the students' stylistic preferences

Figure 1. *The stylistic development as the students progress through university*

On the other hand, the 4th years appeared to have a weaker preference than the postgraduates for ‘legislative’ (U = 378.5, $p < .05$, r = -.30), ‘executive’ (U = 280.5, $p < .001$, r = -.30), and ‘global’ (U = 280.5, $p < .05$, r = -.30), as well as a stronger preference for ‘hierarchic’(U = 346, $p < .01$, r = -.34) and ‘oligarchic’(U = 206.5, $p < .001$, r = -.54). In general, these findings are in accordance with the results of our first comparison between postgraduates and the undergraduates. Nevertheless, it should be noted that although the thinking styles of both year groups seem to compare in a similar manner with the thinking styles of the postgraduates, there is a difference: the fourth years do *not* significantly differ from the postgraduates in their preference for ‘conservative’ thinking.

Regarding the undergraduates’ attainment, the Spearman correlations were computed and no significant correlations were found between the undergraduates’ thinking styles and the total number of courses that each participant had passed. However, when looking for correlations between thinking styles and the average exam grades of the courses the undergraduates passed, two significant positive correlations were found with ‘liberal’ thinking (r_s = .150, $p < .05$) and ‘anarchic’ thinking (r_s = .143, $p < .05$). Similarly, when looking within each year group no significant correlations between thinking styles and the number of courses the students passed was found for 2nd and 3rd year students.

Moreover, for the 2nd year students, there was a positive correlation between average grade and ‘judicial’ thinking style (r_s = .222, $p < .05$) and, for the 3rd year students, average grade was negatively correlated with ‘conservative’ thinking style (r_s = -.286, $p < .05$). However, for the 4th years ‘judicial’ thinking style was found to be correlated positively with the number of courses the students passed (r_s = .380, $p < .05$). No significant correlations were found between the thinking styles of the 4th year students and the average grade of the courses they had passed.

5. Discussion

While these results may seem complex, there is a coherence to them which provides a framework for comparing different groups – that is, the thinking style *types* developed by Zhang and Sternberg (2006) and especially the contrast between Type I and Type II thinking styles. Note that Type I thinking styles are linked with preference for originality and freedom in thinking, low degrees of structure and more complex information processing, while Type II styles are linked with preference for conformity, structured tasks, authority and straightforward information processing. This typology alone does not account for our findings, since it does not include the difference we uncovered between ‘hierarchic’ preferences (see §4.1.). Thus we introduce the modified terms ‘Core I’ and ‘Core II’: *Core I thinking styles* (which includes Type I thinking styles and the thinking styles linked with non-prioritised thinking), and *Core II thinking styles* (which includes Type II thinking styles and the thinking styles linked with prioritised thinking). We shall argue that adopting the Core I/Core II terminology can help us in gaining further understanding about the results of this study.

Thus the findings of this study can be summarised as follows:

- Regarding the intra-undergraduate stylistic development
    - Finding 1a: As students progress through university they develop a stronger preference for Core I thinking styles and/or weaker preference for Core II thinking styles.
    - Finding 1b: Core I thinking styles appear to have a positive effect on the students’ attainment; mainly on the students’ grades and secondarily on the total number of courses the students pass.
- Regarding the postgraduate/undergraduate stylistic contrast
    - Finding 2a: The postgraduates show stronger preference for Core I thinking styles and/or weaker preference for Core II thinking styles.
    - Finding 2b: The postgraduates show an unexpected (based on theory, the findings of previous studies and the findings of this study) preference for ‘executive’ thinking.

This reinforces findings of our previous study for less ‘local’ and ‘conservative’ preferences (Moutsios-Rentzos & Simpson, 2005): the postgraduates show a weaker preference for ‘Core II’ thinking styles than the undergraduates. This shows that the findings of our previous study are in line with the stylistic trends identified in this paper. Thus these stylistic trends may give a first indication of the effect that studying university mathematics has on the students' thinking styles. This is supported by the fact that the fourth years appear to be stylistically 'closer' to the postgraduates. For example, the fourth years and the postgraduates do not significantly differ in the 'conservative' thinking preference (unlike 2nd years). Consequently, the fact that the trends away from Core II thinking styles and/or towards Core I thinking styles can be found throughout all undergraduate year groups *and* the postgraduates suggests that the change in thinking style in this direction is a general outcome of university mathematics education and not related specifically to the transition to graduate study.

Though the two stylistic trends hold true for both intra-undergraduate contrasts *and* the undergraduate-postgraduate contrast, there is one stark *exception*. The postgraduates seem to hold a stronger preference for implementing rules and instructions ('executive'), which is a Core II thinking style. Moreover, the postgraduates appear to have a significantly greater preference for 'executive' thinking than both the second and the fourth year students. This result is unexpected based on both the general thinking styles research (Zhang & Sternberg, 2001) and the factor analysis of this study which assigns 'executive' as a Core II thinking style.

In order to gain better understanding of this unexpected finding, we considered in our analysis the findings regarding the attainment of the undergraduate students and the Core I/Core II terminology. It appears that two Core I thinking styles ('liberal' and 'anarchic') were positively correlated with the average grade of the courses the students had passed. Further analyses revealed that a Core I thinking style ('judicial') was positively correlated with the average grades of the second years and the total number of courses the fourth years had passed. Nevertheless, when we considered the whole undergraduate sample, no significant correlations were found between the total number of courses the students had passed and any of the thinking styles. On the other hand, a Core II thinking style ('conservative') was negatively correlated with the average grade of the courses the second years had passed. Thus, Core I thinking styles appear to be positively related with the students' attainment. Further research would be needed to gain a deeper understanding of the links between attainment and style, though it can be hypothesised that the students following a postgraduate degree in mathematics would most probably have a thinking styles range with higher Core I styles, since this is correlated with higher attainment and thus a better degree, which is crucial for entering a postgraduate programme.

We suggest that the 'unexpected' Finding 2b is related to the special characteristics of the transition to postgraduate study. First, we have to consider the population from which the undergraduates derive: *high attaining mathematics graduates*. The postgraduates' stronger preference for Core I and weaker preference for Core II thinking styles (Finding 2a) can be viewed as a result of the fact that the postgraduates are 'mathematics graduates' (the effect described in Finding 1a) combined with the fact that they are 'high attaining' (Finding 1b). Hence, the Finding 2a can be viewed as an outcome of studying university mathematics and not as being special to those choosing a postgraduate degree.

On the other hand, the unexpected Finding 2b *appears* to be in contrast with the rationale that helped us to explain Finding 2a. We suggest there are two main factors at work, which have complementary effects. First, these stylistic characteristics might be special to the *type of student* who will choose further study disproportionately over other life choices, which is in accordance with our findings about stylistic developments and attainment. For the second factor, we consider Duffin and Simpson (2002) who, based on their more general view of cognitive style in mathematics, hypothesized that the existing university educational system might favour students with a more 'executive' thinking style preference. Though the findings of this study do not support this claim regarding attainment in general, it may be that the 'very high' attaining students, such as the postgraduates, may have such thinking preferences. A student with a Core I thinking preference combined with an 'executive' preference possesses a theoretically powerful stylistic combination, which can help the student to successfully survive the cognitive demands of university mathematics *and* of the examinations involved. We hypothesise that the first or the second factor (or most probably a mixture of both of these factors) may account for the stronger 'executive' thinking preference of the postgraduates.

6. Conclusion

In conclusion, it seems that studying mathematics appears to be linked to originality and freedom in thinking, low degrees of structure and more complex information processing, combined with non-prioritised thinking. This finding may be an outcome of studying university mathematics, which could be linked to the abstract and often counter-intuitive nature of mathematics. Finally, considering the students who choose to follow a postgraduate degree in mathematics, it appears that these 'stylistic' preferences are combined with a preference for 'executive' thinking. This theoretically 'powerful' way of surviving university and/or the type of students that actually choose a postgraduate degree could account for the success of these students.

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