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Change over Time in Spatial Ability of Students Entering University – Impact of Revision of National Curriculum Guidelines up to High Schools

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Abstract. Impact of revision of the national curriculum guidelines of graphic science related contents up to high schools on learning retention of students entering university was investigated by a questionnaire survey at the University of Tokyo. Impact of the revision on spatial ability of students was also analyzed by a Mental Cutting Test (MCT) performed at the University of Tokyo and at Nihon University. The results of Nihon University were compared with those of Meisei University. The principal results are as follows:
1) Learning retention of graphic science related contents fell down sharply after the implementation of the current national curriculum guidelines.
2) The MCT scores at the University of Tokyo did not fall, while the scores at Nihon University fell significantly after the implementation. These results suggested that the implementation might cause a decrease of the spatial ability of students.
3) The MCT scores just before the implementation of the current guidelines were significantly lower than those in around 1990 at both universities. The decrease of the scores could be explained by the decreases of their university admission test deviation scores caused by the increase of university enrollment rate from 1990s to 2000s, suggesting that the revision of the national curriculum guidelines in this period might not cause the decreases of the spatial abilities of students.

Keywords: geometry and graphics education, spatial ability

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1. Introduction

The purpose of graphic science education [4] is to teach graphic representation and geometric construction of solids, and through this instruction, enhance students' spatial ability. Surveys of students' spatial ability have been made by performing mental cutting tests (below referred to as "MCT") since the late 1980s, and it has been reported that teaching graphic science greatly increases MCT scores, that there are great gaps in average scores at the time of university admission between universities, and that there is an extremely high positive correlation between university admission test deviation scores and MCT scores [5]. These results suggest that education related to graphic science up to high schools may impact the enhancing of spatial ability.

Education up to high schools in Japan is stipulated by national curriculum guidelines, which are revised approximately every 10 years. The guidelines revised in 1998/1999 (below called "current guidelines") have sharply cut educational contents and educational time under the policy of so-called "relaxed education". Even in the content of graphic science related education, for examples, solids which has been taught at the fourth year of elementary school has been postponed to the sixth year, orthographic drawing which had been taught part of technology and home economics in the first year of junior high school and as part of mathematics in the same year have been eliminated, and the handling of solids based on vector equations in high school mathematics has also been removed. In addition, educational hours have also been sharply reduced. It is, therefore, important to examine how these reductions of educational content and educational hours by the current guidelines are impacting students' spatial ability.

This research included surveys of learning retention of graphic science related subjects at the University of Tokyo before and after students educated under the current guidelines entered university, and the performance of MCT at the University of Tokyo and at Nihon University to study the relationship between the performance of MCT and changes in learning retention caused by the revision of the guidelines.

2. Survey method

2.1. Learning retention of graphic science related subjects

To investigate how the learning retention of educational contents related to graphic science up to high school has been changed by the implementation of the current guideline, questionnaire surveys were carried out from 2003 until 2008, which are the years corresponding to the period before and after students educated under the current guidelines entered university. The survey was targeted at science/engineering students in the College of Arts and Sciences, the University of Tokyo, and carried out during guidance in Graphic Science I (start of courses in the first year winter semester). The number of students surveyed varied from year to year, but remained between 100 and 130.

The questionnaire survey first asked the respondents, "Did you study each of the following four graphic representation methods: sketch drawing, orthographic drawing, cabinet drawing, and isometric drawing?" and had them select one of three answers: "Yes", "No", and "don't know (if I studied them or not)".

The next question asked was "The positional relationships of two straight lines in a space are classified into three cases. Write these down". The final question asked, "Did you, up to high school, study the three items:

1) vector equations to express a line in a space,
2) vector equations to express a plane in a space, and
3) calculating the intersection point of a line and a plane using vector equations?" and had them select one of three answers: "Yes", "No", and "don't know (if I studied them)". Students who answered "Yes" were asked to describe each type of vector equations and apply them to calculate the intersection point.

2.2. MCT survey

In the College of Arts and Sciences, the University of Tokyo, MCT [5] surveys were performed regularly from 1988 until 2008. A sample problem of the MCT is shown in Fig. 1. The full score of the MCT was 25. The surveys were carried out during guidance in Graphic Science I (start of courses in the first year winter semester, October), and the analysis performed in this paper was for science/engineering male students. The numbers varied from year to year, but ranged from 60 to 230 students.

In the Faculty of Industrial Technology, Nihon University, MCT was performed for first year students from 2004 to 2006. This test was done in early October during Basic Computer Calculation and Computer Presentation. Both were elective courses, and most of the students were studying architectural engineering and mathematical information engineering. During the period between their admission to university and the period when the survey was conducted, they were given no classes in graphic science etc. which might improve their MCT scores. The analysis was made for male students. The number varied from year to year, but ranged from 80 to 110 students.

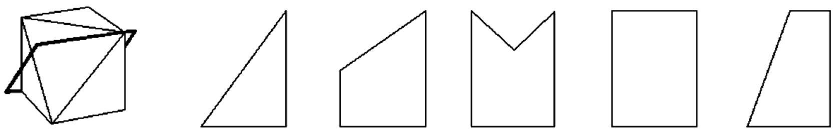

Figure 1: A sample problem of the MCT

3. Results and Discussion

3.1. Learning retention of graphic science related subjects

The results of the survey of learning retention of graphic science related subjects are shown in Fig. 2 for graphic representation, in Fig. 3 for positional relationships of two straight lines and in Fig. 4 for handling of vector equations in a space. The year of admission to university of students educated under the current junior high school and high school guidelines was 2006 and later (under the elementary school guidelines 2009 and later).

a. Graphic representation

As shown in Fig. 2, in 2003 and 2004, the learning rates for sketch drawing and orthographic drawing were about 70%, while for cabinet drawing and isometric drawing, they were about 30%. Students at this time had been educated under the 1989 revised guidelines (below referred to as the "old guidelines"), and the guidelines stipulated "they study drawings necessary for production (orthographic, cabinet, and isometric drawings)" in junior high school technology and home economics. Their learning retention is, however, low. It is difficult to state that this guidance was sufficiently effective.

The sketch drawing learning rate fell to between 40% and 60% beginning in 2006. There is a significant difference between 2003 to 2004 and 2006 to 2008 ($P < 0.05$). Sketch drawing is taught in elementary schools under the old and current guidelines, and although students educated under the current guidelines entered university in 2009, the learning rate had already fallen in 2006.

The learning rate of orthographic drawing fell sharply between 40% and 50% beginning in 2006. There is a significant difference between 2003 to 2004 and 2006 to 2008 ($P < 0.05$). Orthographic drawing was, under the old guidelines, taught as part of operational activities for solids in mathematics and as part of production drawings in technology and home economics in the first year of junior high school, but both have been removed from the current guidelines. The fall of the learning rate which began in 2006 may be the result of the revision of the guidelines. Even in 2008 after they were removed, orthogonal drawing was, however, taught to about 50% of the students. The guideline was partially revised in 2003, permitting contents outside its range to be taught, so that although orthographical drawing was cut from the guidelines, it is thought that orthographical drawing was taught in some junior high schools.

The learning rate of cabinet drawing and isometric drawing fell to 10% to 20% and 20% to 30%, respectively, beginning in 2006. Even under the current guidelines, it is stipulated that in first year junior high school technology and home economics, "either isometric drawing or cabinet drawing is handled (as drawings necessary for production)". However, the learning retention related to these fell even lower.

b. Positional relationships of two straight lines

Figure 3, which concerns the question concerning positional relationships of two straight lines, shows the rates of students who correctly gave all three relationships: "parallel, intersection, and skew position". Under the current guidelines, the positional relationship of two straight lines is taught in mathematics in first year junior high school just as it was under the old

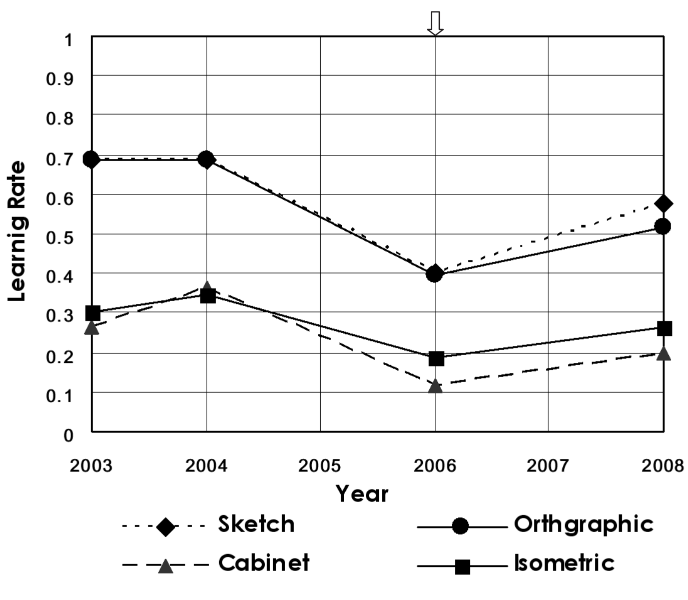

Figure 2: Learning rate for graphic representation
(⇩: The year of admission to university of students educated under the current guidelines)

guidelines. Even in the survey of 2003 and 2004 under the old guidelines, about 30% of the students had a vague understanding of the positional relationships of two straight lines, which are the most fundamental aspects of solid geometry, so it cannot be stated that the retention of learning is high.

Although no change was found in 2006 immediately after the revision of the guidelines, in 2008 the rate who answered correctly fell by about 10% ($P < 0.05$). Under both the old and current guidelines, it is stipulated that "deepen understanding of solids through a variety of operational activities on solids". But among "cutting, projecting, and developing" which must be handled under the old guidelines, cutting and projection were removed under the current guidelines. Operational activities are extremely important for deepening the understanding solids, and it is possible that dropping educational contents concerning operational activities reduced understanding of solid geometry.

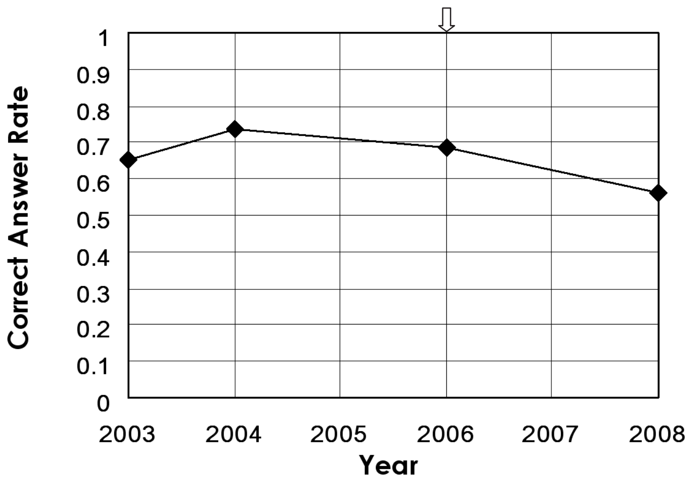

Figure 3: Learning rate for relationship of straight lines
(⇩: The year of admission to university of students educated under the current guidelines)

c. Vector equations in a space

As shown in Fig. 4, in 2003 and 2004 under the old guidelines (revised in 1989), the rate of students who answered that they had studied vector equations for a line, a plane and intersection between a line and a plane were about 75%, about 60% and about 20%, respectively. Students who correctly answered them were about 60%, about 50% and about 3%, respectively. In the old guidelines, high school mathematics stipulated that "vector equations are not dealt with deeply", and many students studied vector equations for a line and a plane, but they had not studied the intersection between them, which is the most fundamental application of these vector equations. A similar questionnaire survey was carried out in 1987, at that time, almost all students correctly answered concerning these vector equations including the calculation of the intersection point. Students in 1987 were educated under the guideline revised in 1977, in which it was stipulated that, "they study vector equations (including a line, a plane, and their applications)". The 1989 revision of the curriculum guideline had reduced scholastic ability concerning vector equations. In 2006 when the subjects were students who received high school education in the first year of implementation of the current guidelines, there was little difference between this year and 2003 and 2004. But in 2008, the rate who had studied the subjects and the rate who answered correctly fell sharply. A comparison of

2006 and earlier years with 2008 shows significant differences ($P < 0.05$) in the rates who answered correctly to the questions concerning equations for a line and plane. Concerning the intersection point, only a few answered correctly each year, but in 2008, not one student answered correctly. In the current guidelines, it is specified that "vector equations in space are not handled", and its implementation was accompanied by a further decline of the retention of learning concerning vector equations. However, in 2008, less than half of the students had learned vector equations, indicating that although they were removed from the guideline, education concerning these was performed in some high schools.

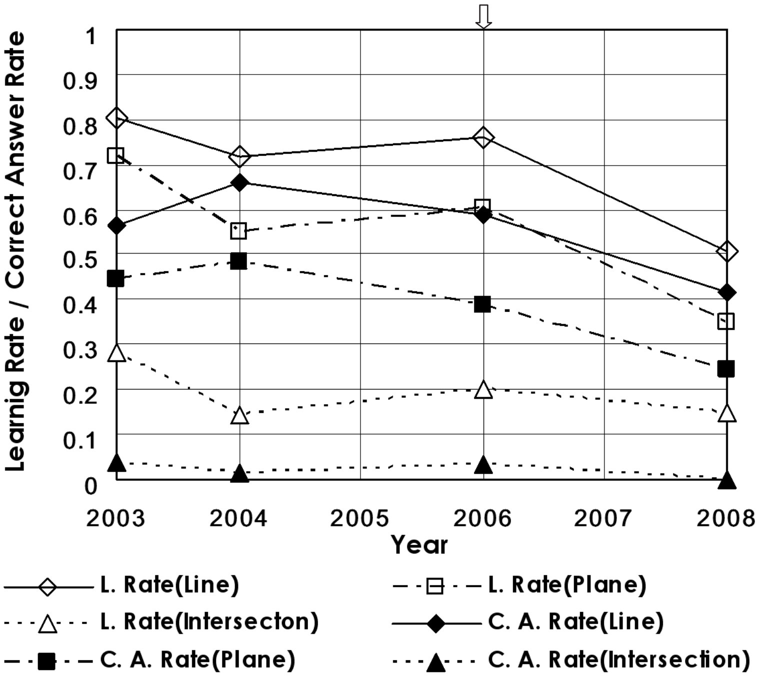

Figure 4: Learning rate and correct answer rate for vector equations in space (⇩: The year of admission to university of students educated under the current guidelines)

As discussed above, it cannot be claimed that retention of learning up to high school of graphic representation and solid geometry were high even under the old guideline. The implementation of the current guideline has further lowered its level.

3.2. Change over time in MCT scores

Table 1 shows the average MCT scores at the University of Tokyo. The overall average score is about 21.4 points. Change over time in the average score is shown in Fig. 5. Table 2 shows the average scores at Nihon University. The overall average score is about 14.5 points, and is lower than that for the University of Tokyo. Change over time in the overall average score is shown in Fig. 5 together with the past survey results for Meisei University (see Section 3.2.2.b).

3.2.1. Changes after implementation of the current guideline

The changes in MCT scores after implementation of the current guideline will be discussed in this section. As already mentioned in Section 3.1, the year of admission to university of students educated under the current guidelines for junior high school and high school is 2006 and later (for elementary school 2009 and later).

Table 1: MCT scores at the University of Tokyo (Science/Engineering, Male)

Year	*Average score*	*S. D.*	*No. of subjects*
1988	22.38	2.20	63
1989	21.58	3.08	158
1990	22.05	2.35	98
1991	21.51	2.64	100
199*	21.48	2.71	207
1995	20.88	3.59	148
1998	21.69	3.44	99
1999	21.69	3.47	127
2000	21.24	3.21	234
2003	21.01	3.55	143
2004	20.85	3.17	135
2005	21.36	2.91	116
2006	21.36	3.13	110
2007	21.13	3.48	111
2008	21.08	3.12	128
Average	21.42	3.07	132

Table 2: MCT scores at Nihon University
(Architectural engineering/Mathematical information engineering, Male)

Year	*Average score*	*S. D.*	*No. of subjects*
2004	15.02	4.48	100
2005	14.72	4.51	106
2006	13.81	4.84	82
Average	14.52	4.61	95

a. University of Tokyo

As shown in Fig. 5 and Table 1, at the University of Tokyo, a tendency for the MCT to fall from its 2003 to 2005 levels beginning in 2006 is not seen. Even looking only at students who entered the university immediately after graduating from high schools (approx. 75%) in the 2006 survey does not reveal any remarkable change in the average score of 21.1 (standard deviation of 3.2 points).

As discussed in Section 3.1, implementing the current guideline reduced the learning retention for graphic science related education up to high schools. However, a decline in spatial ability of students resulting from this reduction was not confirmed.

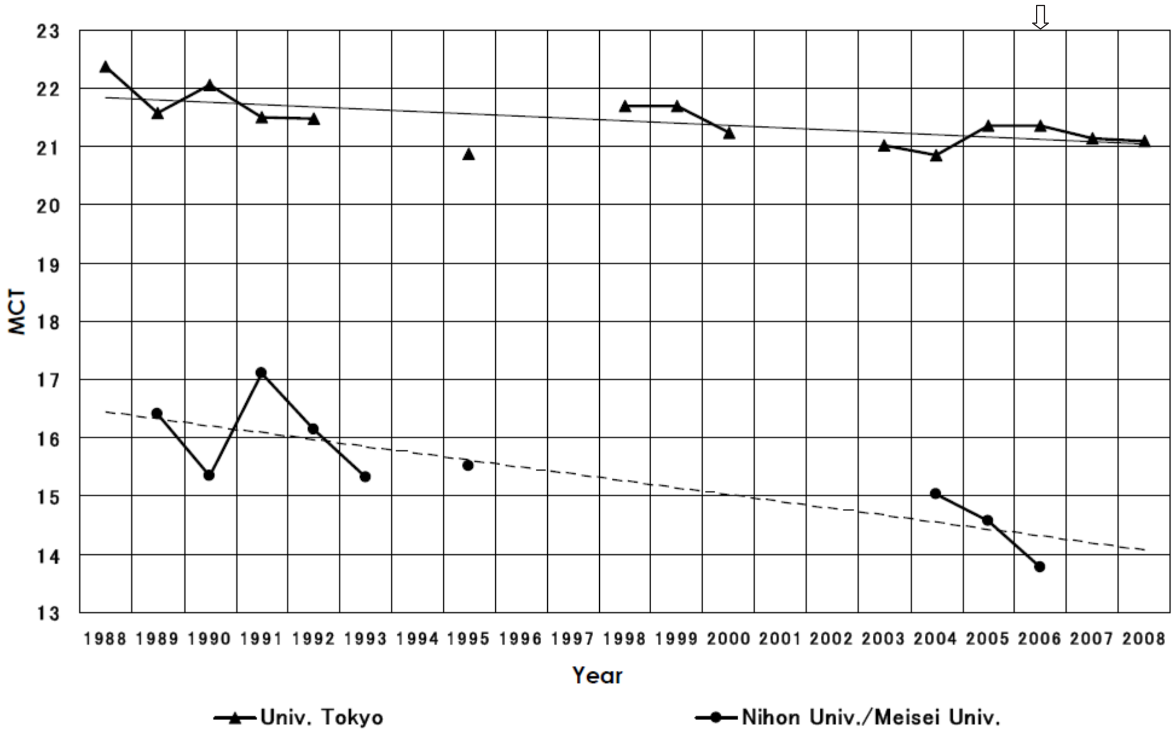

Figure 5: Change over time in MCT scores (Full score: 25,
(⇩: The year of admission to university of students educated under the current guidelines)

b. Nihon University

As shown in Fig. 5 and Table 2, the MCT score in 2006 at Nihon University fell about 1.2 points from the score in 2004; a significant difference ($P < 0.05$). And even compared with 2005, a significant difference of about 1 point is seen ($P < 0.05$). As shown in these results, the survey at Nihon University revealed a different trend from that seen at the University of Tokyo, confirming that spatial ability tended to fall between 2004 and 2006.

At Nihon University, learning retention was not surveyed, so the retention of education up to high school is not clear. However, as seen in the learning retention survey at the University of Tokyo described in Section 3.1, it is well assumed that implementation of the current guidelines has also lowered the learning retention at Nihon University. Under the current guidelines, cutting and projection are removed in junior high school, and guidelines stipulate that mathematics in high school, “contents are selected appropriately according to students’ status and number of units”, and overall, it stresses “relaxed education” according to the “actual status of students”. Furthermore, the revision of the guidelines in 2003 revised the position of the guidelines to the “minimum standard”, so when there is leeway, contents exceeding the range can be taught. As a result, it may be possible that differences in scholastic ability between schools up to the high school level have increased, sharply lowering scholastic ability in overall mathematical education including graphic science related subjects, and reducing spatial ability among students of Nihon University which has a medium scholastic ability level (university admission test deviation score: ~ 44) below that of students at the University of Tokyo which has a high scholastic ability level (university admission test deviation score: ~ 68).

3.2.2. Long-term change prior to the implementation of the current guidelines

In this section, the long term changes in the MCT score between approximately 1990 and 2005 just before the implementation of the current guidelines will be discussed.

a. University of Tokyo

Table 3 presents the MCT average scores indicated by five years of data from 1988 to 1992 and by three years of data from 2003 to 2005 for the University of Tokyo. During the years from 2003 to 2005, the average score was down about 0.7 points from that of 1988–1992. The difference in the score is not great, but because the standard deviation is small, the difference is significant ($P < 0.01$) ($t = 3.3$). MCT scores are known to be highly correlated with the university admission test deviation score (hereafter, referred as "UATDS") (correlation coefficient of 0.92 for males in science and engineering universities, see Fig. 6) [5]. Assuming that the UATDS represents overall scholastic ability, the high correlation of the MCT score and UATDS shows that there is a high correlation between MCT scores and overall scholastic ability. The UATDS is calculated for each year, so if the university-enrollment rate rises, high school graduates with lower scholastic ability can qualify for university, reducing the scholastic ability, even if the UATDS in each year remains the same. During the period from 1988 to 2005 when the surveys were conducted, the university enrollment rate soared (36.7% to 51.5%). Consequently, if long-term MCT scores are compared with the UATDS as a criterion for overall scholastic ability, it is necessary to convert UATDS considering the change in the university enrollment rate [3].

Table 3: MCT scores at the University of Tokyo (Science/Engineering, Male)

	1988–1992	*2003–2005*	*Diff.*
Average	21.73	21.06	0.67
S. D.	2.72	3.24	–
No. of subjects	504	392	–

The UATDS for the University of Tokyo was almost constant at 68 during the survey period, but it fell about 1.1 from 1988–1992 to 2003–2005. If the UATDS is converted considering the change in the university enrollment rate in this period, it causes additional falls about 1.3. The 2.4 fall obtained by totaling these is the UATDS change. Using linear approximation in Fig. 6, which shows the correlation of the UATDS and MCT score, the UATDS fall of about 2.4 becomes a fall of about 0.54 points in the MCT scores, which is a value approximately as great as the fall shown in Table 3. Thus the fall of the MCT score observed by surveys of the University of Tokyo from 1988 to 2005 can be explained as the result of the change in the UATDS caused mainly by the rise of the university enrollment rate.

b. Nihon University – Comparison with Meisei University

In the years prior to the implementation of the current guidelines (2004 and 2005), the UATDS in the Faculty of Industrial Technology of Nihon University was about 44. At this university, an MCT survey was not performed around 1990. To examine its long-term change, the results

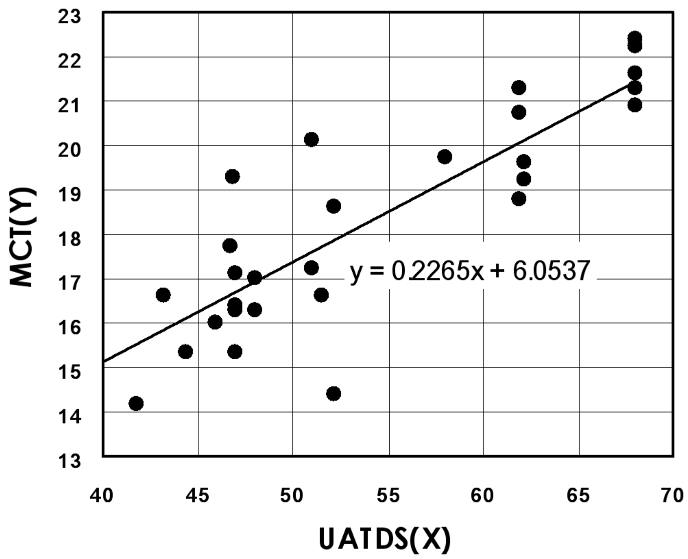

Figure 6: Average MCT scores as a function of UATDS
(Science/Engineering, Male, Re-plotted from the data in Ref. 5)

were compared with the results of a survey of MCT performed by Saito et al. [1, 2] at the Faculty of Sciences and Engineering of Meisei University from 1989 to 1995, selected as results of a MCT survey at a university with about the same UATDS as the Faculty of Industrial Technology of Nihon University. As shown in Table 4, the UATDS of the Faculty of Sciences and Engineering of Meisei University was an average of 45.1 at that time, which was almost the same as the UATDS in 2004 and 2005 in the Faculty of Industrial Technology of Nihon University.

Table 4 and Fig. 5 show the MCT scores at Meisei University. The average score at Meisei University in the 1990s was 15.9, which is 1.1 higher than the average of 14.8 points at Nihon University in the 2000s (Table 2): a statistically significant difference ($P < 0.01$). A comparison of the MCT scores at Nihon University and Meisei University, where the UATDS at the time of the survey were almost identical, shows that the MCT scores fell between the 1990s and 2000s.

Table 4 shows the values obtained by converting the UATDS in the survey year at Meisei University to those for 2004 and 2005 when the survey was performed at the Faculty of Industrial Technology of Nihon University. The table shows that the average value of the UATDS converted to 2004 to 2005 is 49.0, showing that it is about 5 higher at Meisei University than at Nihon University. This difference corresponds to MCT scores of 1.1, equal to the 1.1 point fall of the MCT score confirmed by the above comparative surveys. Thus the fall of the MCT score confirmed by the comparative surveys at Nihon University and Meisei University from 1999 to 2005 can be explained as primarily the result of the change in the UATDS caused by the rise of the university enrollment rate.

The students from 1988 to 1995 were educated under the guideline revised in 1977, and the students from 2003 to 2005 were educated under the guideline revised in 1989. The contents of graphic science related education under these guidelines are basically unchanged in elementary and junior high schools. The handling of vector equations in high school mathematics is, however, changed from "vector equations for a line, plane and their applications are studied" (1977 revision) to "the handling of vector equations is not dealt with deeply" (1989 revision). As discussed in this section, the MCT scores have fallen both at the University of Tokyo

Table 4: MCT scores and UATDS at Meisei University [1, 2].
Almost all the students are male (Female ≤ 5%)

Depart-ment	*Year*	*Average*	*S. D.*	*No. of students*	*UATDS*	*Converted UATDS*
M*	1989	16.41	4.43	129	43.7	49.3
	1990	15.34	4.42	167	43.7	49.3
	1991	17.10	4.20	157	46.2	50.5
	1992	16.29	4.36	177	47.5	51.1
	1995	16.79	4.67	85	46.0	47.9
C**	1992	15.98	4.91	146	46.5	50.3
	1993	15.32	4.93	158	45.5	48.9
	1995	14.24	4.46	119	42.0	44.7
Average		15.93	4.55	142	45.1	49.0

* Mechanical engineering
** Civil engineering

and at Nihon University / Meisei University, but the scale of the fall can be explained as that based primarily on the changes in UATDS, suggesting that the revision of the guideline in 1989 does not greatly impact spatial ability of students.

4. Summary and Conclusions

This research included a questionnaire survey performed at the University of Tokyo in order to investigate the learning retention rate of graphic science related education up to high school accompanying the implementation of the current curriculum guidelines. And in order to investigate changes in spatial ability accompanying the revision of the guidelines, MCT surveys were carried out at the University of Tokyo and Nihon University, and the results of the survey at Nihon University were compared with the results of past surveys at Meisei University. Principal results are as follows.

The learning retention of graphic science related subjects up to high school could not be described as high even under the old guidelines, but fell further with the implementation of the current guidelines.

MCT surveys of students before and after implementation of the current guidelines have not revealed any change in the average MCT scores at the University of Tokyo. On the other hand, at Nihon University, the average score has fallen significantly. It is possible that education under the current guidelines increased the gap in scholastic ability between schools up to the high-school level, and scholastic ability in mathematics including graphic science related subjects fell even lower among students of Nihon University with its medium scholastic ability level than among students of the University of Tokyo with its high scholastic ability level, impacting the decline of spatial ability measured by the MCT.

An examination of long-term change over time in average MCT scores of students prior to the implementation of the current guidelines shows that at the University of Tokyo, the average score had fallen in 2000 to 2005 below the level around 1990. And a comparison of the Nihon University survey results conducted in 2004 to 2005 with the survey results of

Meisei University conducted between 1990 and 1995 also reveals a decline of the MCT score. The breadth of the decline of these average MCT scores can be explained as the result of a change in the university admission test deviation scores caused by the rise of the university enrollment rate, suggesting that the revision of the national curriculum guidelines in this period might not cause the decreases of the spatial abilities of students.

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