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ABSTRACT

In 1995, the state of Minnesota participated in the Third International Mathematics and Science Study (TIMSS), oversampling students to permit comparison with the United States as a whole and with other participating nations. The data generated by the assessment and its subsequent analyses provide informative insights as well as suggest questions for further exploration. In general, the results for Minnesota students were similar to those for the U.S. as a whole. Both Minnesota and the U.S. showed higher scores relative to other participating nations at the fourth grade, and declining relative scores at grades eight and twelve. Minnesota scores tended to be slightly higher than those for the U.S., and the decline in scores at grades eight and twelve was not as sharp in Minnesota as for the U.S. as a whole. There was, however, an exception in Minnesota science scores at the eighth grade level that led the Goals Panel to commission this study. This case study is an in-depth examination of why eighth grade science students in Minnesota were second only to Singapore in TIMSS. This study identifies several characteristics of science education that are unique to Minnesota that explain the state's world-class performance in eighth grade science. These characteristics include high expectations for all students, focus and coherence of curriculum, alignment fostered by the existence of "de facto" science standards, continuity, and capacity within the teaching profession. (ASK)

Minnesota & TIMSS

Exploring High Achievement in Eighth Grade Science

NATIONAL
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GOALS
PANEL

Autumn 2000

Lessons
from the States

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Minnesota & TIMSS

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This report is commissioned by the National Education Goals Panel. The opinions expressed in this paper are those of the authors and do no necessarily reflect the views of the Goals Panel or its members.

National Education Goals Panel staff members, Burt Glassman and Emily Wurtz contributed to the development of this document.

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Foreword

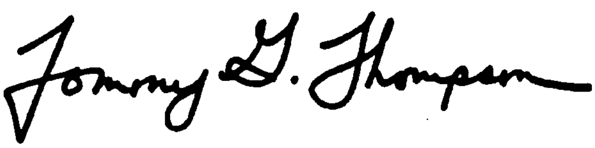
I am pleased to present the latest report in the National Education Goals Panel's "Lessons from the States" series. The Goals Panel's intent for this series of publications is to identify and document examples of successful education reform and improvement. Through analysis, we are providing educators and policymakers with findings that can inform their decisions and, we hope, help accelerate their students' journey to academic excellence.

Minnesota's participation in the Third International Mathematics and Science Study (TIMSS) in 1995 demonstrates the value of international benchmarking and proves well designed assessments provide much more than raw scores and rankings. The in-depth analyses of Minnesota's TIMSS results by Bill Schmidt, SciMath MN, the authors of this report and others have generated information that can guide teachers, principals, and policymakers in developing standards, designing curriculum and evaluating instructional approaches.

Minnesota's experience also validates the benefits of standards-based reform. Although Minnesota did not have formal state standards at the time TIMSS was administered, Houang, Schmidt and Cogan point out that *de facto* standards existed in science and "they functioned in much the same way" as a formal set of standards. The performance of Minnesota students in science, particularly in the 8th grade, resulted, in part, from focus, coherence and alignment in the educational system—exactly the objectives of a comprehensive system of standards-based reform.

This report also points out the next set of challenges before us. Standards, assessments and accountability are the beginning of the journey. We must next seek to create alignment in our systems among curriculum, textbooks, instruction, and learning opportunities for teachers if we are to move our academic performance to world-class levels. The Minnesota experience shows that it can be done. The study provides ample documentation that clear and coherent state strategies can improve academic learning. We must stay the course and take the necessary steps to get there.

I commend this report to your attention in the sincere hope you will find information and ideas to assist you in your ongoing efforts to improve education for all of our children.



Tommy G. Thompson
Governor of Wisconsin
2000 Chair, National Education Goals Panel

Minnesota & TIMSS

Exploring High Achievement in Eighth Grade Science

By John Barth

An Overview

In 1995, the state of Minnesota participated in the Third International Mathematics and Science Study (TIMSS), oversampling students to permit comparison with the United States as a whole and with other participating nations. The data generated by the assessment and subsequent analyses of them provide informative insights as well as suggest questions for further exploration.

In general, the results for Minnesota students were similar to those for the U.S. as a whole. Both Minnesota and the U.S. showed higher scores relative to other participating nations at the fourth grade and declining relative scores at grades eight and twelve. Minnesota scores tended to be slightly higher than those for the U.S., and the decline in scores at grades eight and twelve was not as sharp in Minnesota as for the U.S. as a whole. There was, however, an exception in Minnesota science scores at the eighth grade that led the Goals Panel to commission this study.

Mathematics Results

In mathematics at the fourth grade, both Minnesota and the U.S. were above the international average but not in the top tier of nations. At the eighth grade, Minnesota remained slightly above the international average while U.S. students fell below it. Minnesota's eighth grade mathematics scores still did not place in the top tier of nations. At the twelfth grade, Minnesota students were slightly below the international average, and the U.S. was significantly below it.

While Minnesota students scored somewhat higher than the rest of the U.S., both show a similar pattern. In mathematics, student performance relative to the other participating nations was highest at fourth grade and showed a decline thereafter. The decline in relative performance for U.S. students appears to begin following the fourth grade. The decline for Minnesota students does not appear to begin until after the eighth grade and is not as large as the rest of the U.S.

Science Results

In science at the fourth grade, Minnesota and the U.S. as a whole were only outperformed by Korea. Minnesota scores were slightly higher but not statistically different from those of the U.S. At the twelfth grade, Minnesota scores declined but remained near the international average. Twelfth grade science scores for the U.S. were in the bottom tier.

A significant exception is apparent in the results for eighth grade science. The pattern for the U.S. is similar to that for mathematics — higher scores in the early grade with a decline relative to the rest of the participating nations in the later grades. In eighth grade science, U.S. students scored at the international average.

The Minnesota results in eighth grade science present a much different picture. Minnesota eighth graders scored significantly higher than the rest of the U.S. Internationally, Minnesota eighth graders were outperformed only by Singapore, one of the highest performing nations overall on TIMSS.

Given the design of TIMSS, these starkly contrasting results in mathematics and science were achieved by essentially the same cohort of Minnesota eighth graders. In mathematics, Minnesota eighth graders' scores were similar to those of the U.S. as a whole and slightly above the international average. Yet, the data clearly show that in science Minnesota eighth graders performed significantly higher.

The Study

Concluding that the exceptional performance in eighth grade science may hold a story informative for educators and education policymakers, the Goals Panel commissioned three papers to explore it. The Panel approached Dr. William Schmidt, Executive Director of the U.S. National Research Center, TIMSS, at Michigan State University, to undertake additional analyses of the Minnesota and other TIMSS data. The Goals Panel also contracted with Dr. Frances Lawrenz, Professor in the Departments of Educational Psychology and Curriculum and Wallace Professor of Teaching and Learning at the University of Minnesota in Minneapolis, to conduct a case study among leaders in mathematics and science education in Minnesota. Finally, the Goals Panel asked Dr. Senta Raizen of the National Center for Improving Science Education to examine the evidence gathered by Lawrenz, Houang, Schmidt and Cogan, and found in other TIMSS analyses and present a synthesis of the findings. In addition, the Goals Panel asked Bill Linder-Scholer, Executive Director of SciMath MN, to comment on the benefits and lessons learned from Minnesota's participation in TIMSS.

The objective was to seek to identify actions and policies that could plausibly explain the differences in performance in mathematics and science by Minnesota eighth graders and their world class performance in science. It is difficult if not impossible in research of this type to identify causal relationships between actions taken and eventual outcomes. In addition, case study interviews, by their very nature, produce impressionistic views of events. However, the Goals Panel believes that the case studies can identify common perceptions that, when overlaid with the data, begin to illuminate the story. Together, the case study and data analysis can point out correlations between actions and results and suggest conclusions that are informative to and actionable by educators and policymakers.

The Findings

The case study and analysis of the TIMSS data suggest a handful of factors that offer plausible explanations for the difference in student performance in mathematics and science and for the world-class performance in 8th grade science. They are:

High Expectations for All Students

All three authors note different overall system expectations for Minnesota students in mathematics and science. Almost all Minnesota students in the 7th and 8th grades took the same science courses, life science in the former and earth science in the latter.

The pattern in mathematics was markedly different. Lawrenz notes that "by the middle grades and high school, mathematics classes were tracked with different students receiving different content." This pattern is common in U.S. mathematics education and results, in Linder-Scholer's words, in "curriculum differentiation and thus mixed 'expectations' for students."

This factor was also identified in an earlier Goals Panel report that looked at achievement gains in North Carolina and Texas. (See *Exploring Rapid Achievement Gains in North Carolina and Texas*, Grissmer and Flanagan, National Education Goals Panel, November, 1998)

Focus and Coherence in Curriculum

One of the values of TIMSS participation was the depth of data available for subsequent analysis. It is possible to break down the disciplines of mathematics and science into topic areas and to examine student scores in each of the topic areas. In addition, TIMSS surveyed teachers in participating countries to gather information on what was taught and how it was taught. These analyses can illuminate critical areas relating to curriculum and instruction.

Earlier analyses of TIMSS data compared the U.S. with other participating nations. The U.S. educational system introduced large numbers of topics each year in mathematics and science, developed few of them to depth, and repeated significant numbers of topics in subsequent school years. In contrast, the highest performing nations introduced far fewer topics in any given school year, developed most of them in depth, and moved on to new topics in subsequent years. The authors of the report on these findings concluded that the United States curriculum in mathematics and science was "a mile wide and an inch deep." (See *A Splintered Vision: An Investigation of U.S. Science and Mathematics Education*, Schmidt, McKnight and Raizen, Kluwer Academic Publishers, 1997)

Houang, Schmidt and Cogan undertook a similar analysis of Minnesota TIMSS data and compared it to the U.S. as a whole and to other participating nations. They found that the

Minnesota curriculum in mathematics and in 4th grade science most closely resembled that of the U.S. as a whole, in short, "a mile wide and an inch deep."

In 7th and 8th grade science in Minnesota, the findings were significantly different. (TIMSS tested students in the two grades that contained the greatest number of 13-year-olds.) Here there were far fewer topics introduced and more time devoted to developing them in depth. This pattern is consistent with the highest performing nations in TIMSS.

The apparent expectation in Minnesota was that all students would take the same science courses in grades 7 and 8. At the time that TIMSS was administered in 1995, Minnesota did not have statewide academic standards. It appears that over time a consensus developed with the profession in Minnesota that life science would be taught in grade 7 and earth science in grade 8, and nearly every school district in the state was in harmony with that consensus. Schmidt, Houang and Cogan suggest that there existed in Minnesota what they term "*de facto* state standards at least in science for grades seven and eight." They further note that: "It is important to keep in mind that from Minnesota's point of view the *de facto* science content standards were not official standards but that from a research point of view aimed toward understanding the Minnesota results they functioned in much the same way."

Schmidt, Houang and Cogan conclude: "Three characteristics discussed elsewhere as lacking in the US curriculum as a whole — focus, coherence, and international rigor — seemed much more to be present for Minnesota science at seventh and eighth grades. Not only is focus present but there is coherence about the science curriculum concentrating on a small number of topics all within a given area that cohered together within the broader sense of the discipline."

Alignment

Based upon the case study interviews, it appears that the emergence of *de facto* standards in science was accompanied by other actions that resulted in greater alignment within science education in Minnesota. Both Schmidt and Lawrenz point to the significance of teacher certification requirements as a potential factor influencing student performance. For example, a certification in earth science was required to teach science in Minnesota in the 8th grade.

It also appears that through a process Lawrenz describes as "incremental but cumulative" a consensus emerged among classroom teachers, teacher educators and state officials as to what constituted good instruction in science. The emerging consensus was influenced by and, in turn further influenced, statewide organizations such as SciMath MN, professional organizations such as the Minnesota Science Teachers Association and state agencies. As a result, when TIMSS was administered in 1995, science teachers in the middle grades were more likely to use the same or similar texts and common instructional practices.

Continuity

The "incremental but cumulative" process noted above occurred over time. Some of the early factors, the influence of which are still present in Minnesota science instruction, date to National Science Foundation science education programs of the 1960s. The critical aspect is that there was time for classroom teachers, administrators and statewide leaders to evaluate various approaches to teaching science and to incorporate, modify or reject various elements based on their apparent effectiveness. There was also time for the developing consensus to gain acceptance with teachers throughout the state and for supporting activities, such as professional development, to align with it.

In contrast, Lawrenz notes that mathematics curriculum and instruction in Minnesota were characterized by repeated "pendulum swings" between new approaches and "back to the basics." At the time that TIMSS was administered, Mathematics education was characterized by numerous, locally developed sets of standards or expectations and curriculum and instruction very similar to the rest of the U.S. Consequently, Minnesota TIMSS scores in mathematics, while slightly better, were not markedly different than the U.S. as a whole.

Capacity within the Profession

The *de facto* science standards that emerged in Minnesota were not the product of official state action but developed organically within the profession of state science teachers and their professional organizations. The same is true for the focus, coherence and alignment that evolved around what science topics were to be taught and how they were to be taught. This suggests positive news about the capacity of education professionals to contribute to overall efforts at educational improvement and of the necessity of integrally involving them in reform and improvement initiatives. It also suggests the necessity of aligning teacher training, professional development and other teacher support mechanisms with the overall reform process.

The Case of Minnesota Mathematics and Science: What Can We Learn?

Senta A. Raizen

National Center for Improving Science Education

In 1995, the U.S., along with 45 other countries, took part in the Third International Mathematics and Science Study (TIMSS), the largest and most extensive study of mathematics and science education ever conducted. TIMSS surveyed student attainment in science and mathematics for 9-year olds (grades 3 and 4 in the U.S.), 13-year olds (grades 7 and 8 in the U.S.), and the final year of school (grade 12 in the U.S.). The results, reported for 41 countries for 13-year olds and for over 20 countries at the other two population levels, were widely publicized in the U.S. and the other participating countries.

In addition, however—and far less publicized—TIMSS is a rich source of data on many contextual factors related to student achievement. These include curricular policy and practice in mathematics and science as expressed in national or regional guidelines and textbooks used, teachers' instructional goals and classroom practices, students' attitudes and home context, school and country contexts, and more. The U.S. has supported the understanding and use of these data by teachers and school administrators to further improvement in science and mathematics education in this country. For example, the U.S Department of Education (1997) has sponsored the development of a toolkit for use of TIMSSS data. More recently, the National Research Council (1999) published the report and accompanying professional development guide: *Global Perspectives for Local Action: Using TIMSS to Improve U.S. Mathematics and Science Education*, and held a convocation for school districts to develop improvement plans based on the extensive TIMSS information resources.

This National Education Goals Panel report has been commissioned with the same aim in view, that is, to advance what we can learn from TIMSS to improve education in this country. Our focus is on the TIMSS results from one U.S. state, Minnesota, which have proved particularly illuminating. Minnesota, along with Colorado and Illinois, participated in TIMSS as a "mini-nation," with sufficiently large sample sizes to provide state-specific results. Moreover, it was the only state that tested students at all three of the TIMSS population levels and in both public and private schools.

Minnesota's educators hoped that the state's participation would make possible two kinds of comparisons: with the U.S. and with other countries. This is indeed the case, but it turns out that perhaps of equal or greater interest is the comparison between students' science and mathematics achievement within Minnesota itself, especially the different results achieved by 8^{th} graders in these two fields. The brief summary that follows will first discuss the more general findings regarding Minnesota, that is, how the state's student achievement and classroom factors compare to those for the U.S. as a whole as well as to other countries. These comparisons provide the context for an examination of the differential performance of Minnesota's students in mathematics and science, particularly at the middle school level. The paper concludes with some possible explanations, drawing on the information collected by TIMSS on curricula, instruction, and other background variables and also on the case study and interviews conducted by Frances Lawrenz in 1999.

Student Achievement in Minnesota

There are several stories to be told about how student achievement in mathematics and science in Minnesota compared to that of U.S. students and students in other participating countries (see Tables 1-5).

Mathematics

- Minnesota mathematics results generally hovered around the international average at all three population levels—slightly above at grades 4 and 8, but slightly below for the 12^{th} grade literacy test.
- This put Minnesota students on a par with U.S. 4^{th} graders, slightly above U.S. 8^{th} graders (though not significantly so), and outperforming their U.S. peers by 12^{th} grade.

- For 4^{th} and 8^{th} grade both Minnesota students and U.S. students ranked in the middle tier of performance (out of three tiers). For 12^{th} grade, Minnesota students maintained this position (though falling slightly in absolute score compared to the international average), but U.S. students as a whole ranked in the lowest tier (SciMath^{MN}, April 1999).

Science

- In science, Minnesota students in 4^{th} grade were outperformed by only one country, Korea. In 8^{th} grade, they ranked near the top of the middle tier of countries, being statistically outperformed only by Singapore. By grade 12, Minnesota students' performance had fallen to just slightly above the international mean.
- Minnesota 4^{th} graders scored 53 points above the international average in science; U.S. 4^{th} graders overall scored 41 points above the international average. Minnesota 8^{th} graders scored 49 points above the international average; U.S. 8^{th} graders scored 18 points above. By contrast, Minnesota 12^{th} graders scored only 11 points above the international average, whereas U.S. students scored 20 points below the international average. (Note that there is a 31 point differential in Minnesota's favor at both the 8^{th} and the 12^{th} grade levels; that is, the relative decreases in students' performance were quite similar for the state and for the U.S. in general.)
- Whereas U.S. student performance mirrored that of Minnesota's students in 4^{th} grade, it was considerably below Minnesota's for both 8^{th} and 12^{th} grade. For both these grades, U.S. students' scores placed them among the lowest tier of countries. Performance of U.S. 8^{th} graders was above the international average, but U.S. 12^{th} graders' performance was well below the international average.
- Minnesota student performance showed a significant gender gap in 12^{th} grade in both science and mathematics favoring males. This matched U.S. data for science, but there was no gender gap in U.S. mathematics scores. Only two other countries showed no gender gap in mathematics at 12^{th} grade; only one country showed no gender gap in science.

Comparing Mathematics and Science Results

The general performance patterns of Minnesota students were similar in mathematics and science: Whereas the rankings for 4^{th} grade achievement and 8^{th} grade achievement in both subjects were relatively the same compared to that of other countries, there was a comparative decline for 12^{th} graders in both science and mathematics. However, at all population levels, science achievement was higher than mathematics achievement in comparison to other countries. These same patterns characterized the achievement of U.S. students in general, though at almost all levels, U.S. results were below those for Minnesota students—the exception being 4^{th} grade mathematics. The higher achievement of Minnesota students was more marked for 4^{th} and 8^{th} grade science than for mathematics:

- In 4^{th} grade mathematics, U.S. results matched Minnesota's; in science, there was a 12-point difference in favor of Minnesota. In mathematics, Minnesota's 4^{th} graders outperformed U.S. 4^{th} graders in 4 of 14 curricular subfields; they were outperformed by U.S. students in 3 subfields. In science, Minnesota 4^{th} graders outperformed their U.S. peers in 13 of 15 subfield and were their approximate equals in the other two.
- In 8^{th} grade mathematics, there was a spread of 25 points in favor of Minnesota; in science, the spread was 31 points. Minnesota 8^{th} graders outperformed their U.S. peers in 12 of 20 subfields. In science, Minnesota 8^{th} graders outperformed their U.S peers in 8 of 17 subfields.
- However, the trend of differentially higher science achievement for Minnesota students compared to their mathematics achievement was not maintained in 12^{th} grade: the spread between Minnesota results and U.S. results was virtually the same in both fields: 34 points in mathematics and 31 points in science.

Thus, while we see a continuing increase from 4^{th} to 8^{th} to 12^{th} grade of the disparity between Minnesota and U.S. student achievement in mathematics, the difference between science and mathematics achievement decreases over the grades.

The difference between the mathematics and the science achievement of Minnesota's students at the middle school level can perhaps be most vividly illustrated by considering the ranking of top-performing students (see Table 5):

- In science, 20 percent of Minnesota 7th and 8th graders scored at a level considered to be the top 10 percent of students in all 41 countries reported by TIMSS; and at least 40 percent (43 percent for 7th graders) reached the top quarter level.
- In mathematics, only about 8 percent of Minnesota 8th graders ranked in the top 10 percent of students across all countries; 12 percent of Minnesota 7th graders achieved this ranking. 25 percent of Minnesota 8th graders reached the top quarter of the international marker level, as did 33 percent of 7th graders.

To some extent this again mirrored the general U.S. pattern, if at higher levels of achievement for Minnesota. In science, 17 percent of U.S. 7th graders and 13 percent of U.S. 8th graders fell into the 10 percent level of international student performance; in mathematics, 7 percent and 5 percent did so, respectively. As to the top quarter, 34 percent of U.S. 7th graders achieved at this level in science, as did 30 percent of U.S. 8th graders. In mathematics, the percentages for U.S. students reaching the top quarter level, were 21 percent for U.S. 7th graders and 18 percent for U.S. 8th graders. The patterns are clear both for Minnesota and the U.S. First, there is a noticeable difference between science and mathematics in favor of higher science achievement compared to other countries. Second, the falling off in achievement so apparent between middle school and high school already manifests itself between 7th and 8th grade.

We are left with several questions:

1. Why is Minnesota's student achievement in both mathematics and science higher than that of U.S. students in general?
2. Why is Minnesota's student achievement at the elementary and middle school levels markedly higher in science than in mathematics, even beyond a similar if smaller difference for U.S. students in general?

3. Why is student achievement comparatively higher in science than in mathematics, both for Minnesota and for the U.S. as a whole?
4. What causes the decline in student achievement relative to other countries between middle school and high school, both in Minnesota and the U.S?

TIMSS does not provide definitive answers, but the contextual information this large-scale study has developed provides some intriguing clues. The TIMSS data together with information from additional studies commissioned by SciMath[MN] (Voelkl, Goodman & Mazzeo, 1997; Voelkl & Mazzeo, 1997) and the Education Goals Panel (Lawrenz, P. XX; Houang, Schmidt & Cogan, p. XX) point to promising directions for improving both science and mathematics education in the states and in the nation. For each of the questions above, we summarize information on potentially critical contextual factors.

Question 1: Minnesota's higher achievement compared to the U.S.
[We will discuss a number of contextual variables under this question and return to them as relevant to Questions 2-4 below.]

First, let us dispose of the "easy" answers to this question. Yes, child poverty—usually associated with lower test scores—was lower in Minnesota in 1995 than in the U.S as a whole: 12.3 percent as compared to 20.8 percent, respectively. And yes, Minnesota had a lower percentage than the U.S. as a whole of minority populations that generally tend to exhibit lower test scores: 4.8 percent versus 16.7 percent African-Americans, respectively, and 2.0 percent versus 14.7 percent Hispanics, respectively.

But were there contextual factors in 1995 (or the immediately preceding years) specific to mathematics and science that might shed light Minnesota's higher achievement relative to the U.S. as a whole?[1] We summarize below information that points to correlations of potential importance between contextual factors and student achievement.[2]

Parent and Student Variables

Interestingly, a number of relevant factors were not different or even favored the U.S. over Minnesota. For example, according to TIMSS data for 8th grade, parent higher education was similar (33 and 31 percent had finished university in the U.S. and Minnesota, respectively), though a higher proportion had finished high school (but not university) in Minnesota (61 percent compared to 54 percent for the U.S.). There was no difference between Minnesota and the U.S. in student or parent attitude on the importance of doing well in science and mathematics, nor in students' perception of how well they were doing or what it took to succeed in these subjects.

There were, however some differences in high-school enrollment (grades 9-12) in higher-level mathematics and science courses.

- In 1994, Minnesota ranked tenth in the nation in enrollment in higher-level mathematics course: 41 percent of the state's students were taking trigonometry /precalculus before graduation; 15 percent were taking calculus. The corresponding data for the U.S. as a whole were 33 percent and 10 percent, respectively.

There was less difference between Minnesota and U.S. in science courses taken by high school students. Minnesota placed 18th among the states in science enrollment and exceeded national enrollments by only 2 percent in chemistry and 4 percent in physics. (Blank and Gruebel, 1995.)[3]

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[1] It should be noted that Minnesota is by no means satisfied with these results. SciMath[MN] (no date) notes that: "Being among the best in the U.S. is not the same as being first in the world...Minnesota's consistently strong performance in mathematics and science compared to the rest of the U.S. looks different in an international context." (p. 1).

[2] Caution is warranted in drawing inferences on causal relationships based on a cross-sectional survey such as TIMSS.

[3] By 1998, U.S. students had overtaken Minnesota's in chemistry enrollment (54 percent nationally versus 42 percent for Minnesota) as well as in physics enrollment (24 percent nationally versus 20 percent in Minnesota). (Blank and Langesen, 1999.)

Teacher Variables

There were some differences in 8^{th} grade teachers' years of experience. For example, in mathematics, 44 percent of Minnesota students had teachers with 0-5 years experience, versus 25 percent for U.S. students in general. In the case of Minnesota, student achievement in the TIMSS mathematics test increased with length of teachers' experience (up to 20years); however, this was not the case for U.S. students in general. In science, the data were reversed, with 30 percent of U.S. students having 8^{th} grade teachers with 0-5 years experience, versus 16 percent Minnesota students. However, little association between teachers' years of experience and TIMSS science test scores was discernible for either the state or the nation.

Teacher preparation may be another important variable.

- Minnesota ranked very high regarding percentage of grades 7-12 teachers whose main assignment was mathematics and who had a major in mathematics or mathematics education—94 percent for the state compared to 72 percent nationally (data for 1994). (Blank and Langesen, 1999.)
- Also, 64 percent of the high school students in the state had mathematics teachers who had taken university math courses in five or six areas; only 11 percent had teachers having taken math courses in zero to two areas. This put Minnesota in the second-highest ranking state in this category. Nationally, the corresponding percentages were 48 and 26 (data for 1991). (Blank and Gruebel, 1995.)
- The disparity in teacher education was about the same in science: 97 percent of Minnesota grades 7-12 teachers whose main assignment was science had a major in science (field not specified) or science education; nationally, the percentage was 74 (data for 1994). (Blank and Langesen, 1999.)

Out of 30 states, Minnesota also had the lowest percentage of female mathematics teachers, fewer than 30 percent compared to over 50 percent nationally. In science, the Minnesota proportion of female teachers was 20-32 percent; nationally, it was 41 percent for female science teachers. Possibly, this might have influenced the TIMSS data on U.S. versus Minnesota gender differences (see above).

Instructional Variables

8th grade teachers in Minnesota did not vary greatly from U.S. teachers in their views on the nature of mathematics or mathematics teaching. Instruction was largely textbook-based. This was also true in science, although the tradition established in Minnesota during the 1960s of hands-on science maintained itself to some extent (Lawrenz, p. XX). In these laboratory activities, Minnesota 8th grade science teachers varied somewhat from U.S. science teachers in general.

- Only 42 percent of Minnesota students had teachers who favored giving students prescriptive and sequential directions for doing science experiments as contrasted to over 80 percent for the U.S. (and the majority of teachers in all but three of 41 countries).

In general, mathematics teachers in Minnesota varied little from those in the U.S. in general in the types of classroom organization they favored. There also was little difference in classroom organization between science teachers in Minnesota and the national sample.

Minnesota teachers did not spend any more time on mathematics than did U.S. teachers in general; the majority spent between 3.5 to less than 5 hours per week. It is interesting to note that in several of the highest-performing countries, the average was less than that—between 2 hours and less than 3.5 hours per week. Comparable data are not available for science.

In 4th grade, there was little difference between Minnesota and U.S. mathematics classrooms regarding the activities that teachers had students engage in, as was also the case for 4th grade science classrooms. This was not as true for 8th grade. Almost half the 8th grade mathematics teachers in Minnesota were characterized as being dominantly concerned with review and seatwork, whereas this was true for only a quarter of the teachers in the U.S. as a whole. However, over a third of the Minnesota mathematics teachers added instruction to the review and seatwork; less than a tenth of teachers did so in the overall U.S. sample.

- In science, over 70 percent of 8th grade teachers in Minnesota added instruction to other activities such as review and seatwork, contrasted to little more than 40 percent of 8th grade teachers who did so in the general U.S. sample.

Curriculum

Probably the most critical variables in differential student performance between Minnesota and the U.S. in general are related to curriculum. TIMSS gives us several lenses through which to view curricular variables: the intended curriculum as reflected in policies, guidelines, and textbooks; the implemented curriculum—what teachers actually teach; and the achieved curriculum—what students actually have learned.

Two important elements of an effective curriculum are focus and coherence (National Research Council, 1999). Focus refers to the attention given to a single topic area; coherence refers to the relationship of topics to each other within and across lessons. As pointed out in a number of reports, the U.S. curriculum in both mathematics and science lacks focus and coherence and, in mathematics in particular, is repetitive (Schmidt, McKnight, and Raizen, 1997; Schmidt et al., 1999). Curricular intentions for Minnesota middle school science exhibit a different pattern, however.

- The pattern of curricular intent in science was similar in Minnesota to that exhibited by countries with top-achieving students in that fewer science topics were intended to be covered throughout grades 1-8 than was the case for the U.S. as a whole

Minnesota teachers seemed to carry out these curricular intentions by covering fewer science topics both at the 4th and 8th grade levels than did U.S. teachers in general.

Results of these patterns of curricular intent and implementation were evident in the science achievement of Minnesota students. Not only were they outperformed by only one country at both 4th and 8th grades,[4] but they also showed considerable growth in a few selected science areas between grades, particularly at the middle school level.

- A number of the topics in which Minnesota students made the greatest gain between 7th and 8th grade related to earth science and environmental and resource issues, curricular areas emphasized in 8th grade science in the state (see below).

Some of the areas in which Minnesota students made the least gain were in life science, a subject taught in 7th grade. This pattern of selective gains across topic areas could be expected to result from a focused curriculum; it is also quite typical of high-performing countries.

On the other hand, the gains made in mathematics by Minnesota students resembled the general U.S. pattern both in elementary and middle school: Students make relatively limited gains across many topics, consistent with an unfocused curriculum in which many topics are "covered" and repeated from grade to grade.

Question 2: Minnesota's Comparatively Higher Achievement in Science than in Mathematics

This is a particularly intriguing question. Since the very same Minnesota students were tested in science as in mathematics, the variables usually cited as powerfully influencing achievement including socioeconomic status, parents' education, race and ethnicity, and prior achievement must be ruled out as explaining this differential achievement.

We have made the point that the Minnesota science curriculum, particularly in middle school, was more focused than was generally the case for the U.S. as a whole or, indeed,

[4] Although in actual mean score, Minnesota ranked behind three other countries in 8th grade science, only Singapore's score was significantly higher.

the Minnesota mathematics curriculum. Also, we noted that some of the 1960s reforms maintained themselves in science, such as hands-on science often carried out in a non-prescriptive manner; this was not the case in mathematics.

How did these differences between the state's science and mathematics curriculum come about? What can state policy makers learn about formulating curricular and instructional policies that will lead to desired improvement in student performance? It should be noted that, at the time of the TIMSS testing, Minnesota did not have in place state standards—now considered by almost all states an absolutely necessary if not sufficient condition for high student achievement. The state did provide curricular guidelines and frameworks, however, albeit not mandatory ones because of the state's strong culture of local autonomy.

Without question, strong leadership at the state level and relative absence of outside pressure served to unify the state's community of science teachers on what subjects to teach when, and which topics to emphasize at each grade. Gradually, a consensus evolved on teaching life science in 7th grade, earth science in 8th grade, and physical science in 9th grade. Indeed, this sequencing of courses showed up in the poorer performance of Minnesota 8th grade students in physical science topics relative to their performance overall—as tended to be the case for U.S. students in general.

According to state leaders, the Minnesota science curriculum also profited by the emphasis on laboratory or hands-on activities and the continued use of some of the 1960s curricula as well as introduction of 1990s reform curricula, including some intended to address the needs of learners previously not well addressed. Moreover, the state provided many opportunities for environmental education outside the regular classroom, with consequent high achievement by Minnesota students in that part of the TIMSS science test.

By contrast, the mathematics curriculum was characterized by less continuity and a swing "back to basics" after the 1960s reforms and again in the 1990s. Although Minnesota did not swing back as far many states in mathematics and by 1995 had begun attempts to implement the NCTM standards, Lawrenz (p. XX) estimates that, at the time of the TIMSS test, "...the typical middle mathematics curriculum would have been 80% algorithmic and 20% conceptual."

Another factor at play was tracking. As in most U.S. school systems, middle school mathematics was tracked in Minnesota, with different levels of mathematics being taught to 7^{th} graders and also to 8^{th} graders, depending on the perceived ability of the students. This meant that students judged to be of lower ability kept taking arithmetic topics over and over and had little opportunity to learn some of the more advanced concepts included in the TIMSS assessment of 13-year olds. Tracking was not the case for science, where all students in grades 7 and 8 were exposed to the same content—life science and earth science, respectively.

Also, mathematics achievement was more frequently assessed in Minnesota schools than was science achievement, though in neither case were the tests high stake. The effects of the more frequent testing in mathematics are unclear. Because of greater exposure, students might have been less motivated toward the TIMSS mathematics test than the TIMSS science test. Alternatively, one might conjecture that the greater practice might have given them an advantage in the mathematics test.

In sum, the most likely explanations for the high achievement in science of Minnesota's middle school students were:

- A focused, coherent science curriculum formulated and agreed to by the science teachers of the state;
- Instruction that involved students in the active doing of science, both in and out of the classroom; and
- Absence of tracking, resulting in the same learning expectations and exposure for all students to science content, concepts, and skills deemed important.

Question 3: Comparatively Higher Achievement in Science than in Mathematics in the U.S., as in Minnesota

The relatively better performance in science than in mathematics characterized student achievement in the U.S. in general, not only in Minnesota, though the differences were not as great nationally. One of the most reasonable explanations for Minnesota, a more focused and coherent science curriculum, does not hold for the U.S. in general. Tracking, however, is as likely a potential explanation nationally as it is for Minnesota. In addition, though, there may be some other variables worthy of consideration, particularly the importance given to mathematics versus science in the participating countries, and the match of the TIMSS test to the U.S. curriculum in the subjects.

Importance of Subject

While TIMSS data are relatively sparse on the emphasis put on the two subjects in different countries, there is some pertinent information. For one thing, unlike the U.S., a number of countries do not start formal science in the early elementary grades, including such top-performing countries in the later grades as Singapore and Japan. Also, student attitude data for some countries demonstrate a distinct difference in their view (and their parents' and friends') on the importance of the two subjects, in favor of mathematics. For example, in Germany, 72 percent of 8th graders thought it was important to do well in science as compared to 93 percent in mathematics; they estimated that the percent for their friends who thought science important was 35 versus 70 in mathematics. Other countries showed similar (if not as great) disparities in student attitude toward science and mathematics. These included Austria, France, Denmark, several of the former Soviet block countries (but not the Russian Federation) and Switzerland—the most extreme case where only 68 percent of 8th graders thought it important to do well in science versus 96 percent who thought so for mathematics. In the U.S., the two subjects were considered by students (and their parents and friends) to be of equal importance.

In the absence of other strong differences between contextual variables in science and in mathematics in the U.S., these data lead to a possible hypothesis regarding the higher science achievement compared to mathematics of U.S. students in general and Minnesota students in particular. It may be that other countries put greater emphasis on the importance of mathematics than on science, for example, through mandated curricula or requirements for high-stakes testing, with consequent perceptions and effort exerted by students.

Test Match

Another tenable hypothesis is that the TIMSS science test was a better match for the U.S. science curriculum than was the mathematics test for the mathematics curriculum. Certainly, the U.S. accepted both sets of tests as appropriate, since they were the product of protracted international negotiations and field trials. Nevertheless, a good case can be made for this hypothesis. Examining curricular intentions and implementation in U.S. mathematics as expressed in U.S. state guidelines, textbooks and teacher reports on topics taught demonstrates that the U.S. middle school curriculum fell far short of several geometry topics taught in other countries and represented on the TIMSS test. This was also the case for topics dealing with equations and formulas relevant to algebra, and to data representation and analysis. (Note, however, that Minnesota students did much better in these latter two categories than did U.S. students as a whole, though not materially so on geometry topics.) As in Minnesota as well, tracking in middle school mathematics certainly aggravated the problem of more limited exposure of U.S. students to mathematical content compared to students in higher-achieving countries.

In science, the disparity between what was tested and the U.S. curriculum at the middle school level was considerably less, appearing mainly in more advanced physical science topics related to energy sources and conversion and to topics dealing with physical change and forces and motion. The gap in physics knowledge exhibited by U.S. students becomes more evident in 12^{th} grade, where even students taking physics ranked squarely on the bottom when compared to their peers in 15 other countries.

Question 4: The Relative Performance Decline of U.S. and Minnesota Students between 8^{th} and 12^{th} Grade

The eclectic curriculum of U.S. high schools allows many students to opt out of the higher-level mathematics and science courses that are required of students in other countries. Even in systems that are tracked at the upper secondary level, as is the case for most countries, these courses are still required, though generally at different levels of academic rigor and practical application. This contrasts with the layer cake approach to the U.S. science curriculum, with three-fourths of the nation's students (four-fifths in Minnesota) never taking any physics course in high school at all.

While state high school graduation requirements tend to mandate more mathematics courses than science courses, there often is no requirement for the level of these courses. Because of early tracking, many students are not able to take advanced high school mathematics courses either. Only about half the students nationally and in Minnesota have taken either a calculus or precalculus course by graduation. (Blank and Langesen, 1999.) Achievement results again demonstrate the disadvantaging of U.S. students, who rank near the bottom both for general mathematics knowledge and advanced mathematics achievement.

We presume that Minnesota wants to build on the achievement of its elementary students in both mathematics and science, and of its middle schoolers in science. If so, the state—as well as the nation—needs to reexamine its science curriculum at the high school level and its mathematics curriculum for both lower and upper secondary school, as well as its tracking practices in mathematics.

References

Blank, R. K., & Gruebel, D. (1995). *State indicators of science and mathematics education 1995: State by state trends and new indicators from the 1993-94 school year.* Washington, DC: Council of Chief State School Officers.

Blank, R. K., & Langesen, D. (1999). *State indicators of science and mathematics education 1999: State by state trends and new indicators from the 1997-98 school year.* Washington, DC: Council of Chief State School Officers.

National Research Council. (1999). *Global perspectives for local action: Using TIMSS to improve U. S. mathematics and science education.* Washington, DC: National Academy Press.

Schmidt, W. H., McKnight, C. C., & Raizen, S. A. (1997). *A splintered vision: An investigation of the U. S. science and mathematics education.* Netherlands: Kluwer Academic Publishers.

Schmidt, W. H., McKnight, C. C., Cogan, L. S., Jakwerth, P. M., & Houang, R. T. (1999). *Facing the consequences: Using TIMSS for a closer look at U. S. mathematics and science education.* Netherlands: Kluwer Academic Publishers.

SciMath^{MN}. (1998). *Minnesota 4th grade results: Third international mathematics and science study (TIMSS).* St. Paul, MN: Author.

SciMath^{MN}. (1999). *Minnesota 12th grade results: Third international mathematics and science study (TIMSS).* St. Paul, MN: Author.

SciMath^{MN}. (no date). *Minnesota TIMSS report: A preliminary summary of results. Third international mathematics and science study.* St. Paul, MN: Author.

Voelkl, K. E., Goodman, M., & Mazzeo, J. (1997). *Mathematics achievement in Minnesota in the middle school years: Results from IEA's Third International Mathematics and Science Study.* Princeton, N. J.: Educational Testing Service.

Voelkl, K. E., & Mazzeo, J. (1997). *Science achievement in Minnesota in the middle school years: Results from IEA's Third International Mathematics and Science Study (TIMSS).* Princeton, N. J.: Educational Testing Service.

Minnesota and TIMSS: Analyses with State Level Policy Implications

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The results of the Third International Mathematics and Science Study (TIMSS) has had a major impact on the United States both in terms of policy and practice. The results for the United States as a whole suggested achievement levels that were not strong by international standards. The story is clear: students in fourth grade did reasonably well in both mathematics and science but by eighth grade that performance had slipped to below the international average in the case of mathematics and to average in the case of science. By the end of secondary school or twelfth grade the US performance was at or near the bottom of the international rankings both in mathematics and in science for both the general literacy and advanced study.

Subsequent reports have indicated that both curriculum and pedagogy may have played important roles in the US's performance. Factors cited in these reports included the lack of both focus and coherence of the US curriculum. In addition, those reports pointed to the repetition within the US curriculum especially across the middle school years and the fact that the middle school curriculum in the United States is not intellectually rigorous by international standards. The US middle school curriculum concentrates on arithmetic and elementary science while in other countries the middle school years reflect the increasingly complex study of algebra, geometry, chemistry and physics.

Reports focusing on the video tape study, as well as questionnaire data reveal that the US instructional approach tends to concentrate on the memorization of facts and the practice of algorithms or other kinds of skills while the same instruction in other countries is aimed at developing conceptual understanding, applying the skills and algorithms to various contexts and in the development of mathematical or scientific reasoning.

These features of the American educational system have been cited in numerous reports and awareness of them has begun to effect national policy with respect to the science and mathematics reform movements. Many of these findings from TIMSS were in fact consistent with the thrust of the reforms already under way. The data helped to provide additional support for these movements but also to further refine that focus as well as to provide new and subtler nuances as to the road that the US reform might take in the future.

This paper addresses the question of how state participation in a large-scale international study can provide information with respect to policy formulation at the state level. To address this issue we examine the data from the state of Minnesota, which participated in TIMSS. By developing a separate state level sample of its schools, a large enough representation of the state was achieved so that comparisons could be made of the state with respect not only to the United States as a whole but to other nations as well.

Separate TIMSS reports for the state of Minnesota were issued by SciMath MN under the direction of Bill Linder-Scholer, which indicated the relative position of Minnesota internationally and suggested the policy implications. The focus of this paper is to extend those analyses by doing additional analyses that have been performed for United States as a whole as well as other countries (see Facing the Consequences). This will facilitate the use of state level data to inform state policymaking. Not only is the purpose of this paper to examine the extent to which a study like TIMSS can provide valuable information for state level policymaking, but it is also designed to explore the specifics for the state of Minnesota given their participation in TIMSS.

Before turning to a summary of the general results for the state of Minnesota, the question of the value of any state such as Minnesota participating in an international study is first examined. Some policy makers would suggest that the cultural context present in other countries bear little or no resemblance to the culture of the United States.

As a result, they argue that it would have little to offer in terms of suggesting possible ways of reforming mathematics and science education in this country. The point of view in this paper is not that the value of such international research is to provide information that allows states to emulate and copy what other countries do, as if that would some how improve education in this country.

The purpose of exploring the Minnesota data in an international context is not to suggest that what is done in the top achieving countries such as Singapore should be done in the state of Minnesota. The instructional practices of a certain nation are part of the culture of that society and as such can not be readily copied an implanted in other societies where the cultures are quite different.

Rather we suggest that through an examination of the educational practices in other countries one can first of all learn that there is no one way that schooling is to be done. In other words, the very definitions and practices associated with what we call school vary tremendously across the 50 some nations studied in TIMSS. This is not necessarily to suggest that any one way is better than another but to open the possibility that there are multiple approaches to this thing that we call school.

For Americans this is to recognize that what we define as schooling in the United States reflects our cultural values and is in fact a choice that we have made; not necessarily an explicit choice but in the case of the United States perhaps an accretion of many choices made over the 200 plus years of our national history. But none the less, how we do schooling is in fact a choice because it is done differently in other countries and therefore, by definition reflects our choice.

Through an examination of the educational practices of other nations we can expose our thinking to the possibilities of doing things differently and if we choose to reform our system what some of the alternatives might be. So it is in this spirit that this paper examines the Minnesota data toward gaining insight as to why Minnesota performed as it did and how that performance differs from the United States as a whole. Even more generally, it examines how a state's participation in a large international study such as TIMSS might be used to help formulate educational policy at the state level.

General Minnesota Achievement Results

Mathematics

Minnesota's performance in mathematics was at the same level as the US as a whole at the fourth grade. Both performed above the international average but not in the top tier of countries. At eighth grade, the Minnesota performance was also the same as the United States at least statistically speaking, although in absolute terms the students of Minnesota performed somewhat higher than their counterparts in the rest of the nation. That performance for Minnesota placed them slightly above the international average but again not among the top achieving nations. By twelfth grade, the typical graduating senior Minnesota student performed around the international average in terms of mathematical literacy. In this case they performed statistically above the United States.

In summary, the Minnesota mathematics results seemed to hover around the international average at all three grade levels; slightly above average at fourth grade and at eighth grade but below at twelfth grade for general mathematical literacy. This implies that Minnesota students showed a gain when compared to US students as a whole over the eight year span. At fourth grade, they were similar to other US students, but by eighth grade Minnesota students were slightly higher than the US as a whole (although not statistically significantly so). By twelfth grade they statistically significantly out performed their counterparts in the rest of the United States. Said in another way, the Minnesota results were similar to that of the United States as a whole through grade eight in that both did reasonably well at fourth grade but their international ranking dropped by the eighth grade. The similarity ends here, since by the end of secondary school Minnesota's students were still around the international average while US students as a whole had fallen near the bottom of the international rankings.

Science

The science results for Minnesota present a startlingly different story than that for mathematics. While in mathematics Minnesota student's performance was very similar to that of the United States as a whole, this is not the case in science. Minnesota students did appreciably better in science especially at the eighth grade. At fourth grade Minnesota like the United States as a whole was statistically out-performed by only one country – South Korea. Although the Minnesota performance was slightly better than that of the US as a whole there were no statistically significant differences between the two.

At eighth grade only Singapore statistically significantly out-performed Minnesota, and Minnesota itself statistically significantly outperformed the rest of the United States. The US performance as a whole was at the international average. In marked contrast to the United States as a whole, Minnesota was near the international average at the end of high school in the general science literacy test, while US students' performance was near the bottom of the international rankings.

Two points seem particularly important to note here. First, in contrast to the US pattern of continuing decline from fourth to twelfth grade, the Minnesota data reflected a pattern of performance which only declined after eighth grade and the decline was not as steep by the end of twelfth grade.

The second point worth noting is the very strong performance on the part of Minnesota students at the eighth grade level. Here students were only outperformed by Singapore, which was the top achieving nation in most parts of the TIMSS study. This is by far in marked contrast to the rest of the United States and represents the only particularly stellar performance on the part of the United States or any of its constituent parts after fourth grade.

The pattern in science over grades four to eight is similar to that of mathematics when comparing Minnesota to the United States — at fourth grade they were essentially the same but at eighth and twelfth grade Minnesota scored higher than the US as a whole. In both mathematics and science Minnesota's performance at twelfth grade is only average internationally. This, in spite of a much higher performance in the earlier grades, implies that Minnesota loses what advantages it had at fourth grade in mathematics just as the US as a whole does and loses what advantages it had in eighth grade in science by the twelfth grade.

It is, however, important to note that even though Minnesota shows a decline after fourth grade in mathematics and after eighth grade in science the decline in relative international standing by the end of twelfth grade is not as appreciable as it was for the US as a whole.

Minnesota Achievement In Specific Content Areas

TIMSS Minnesota achievement reporting thus far has been limited to global mathematics and science scale scores. These reporting categories are broad and, as a result, include somewhat disparate items from different areas of mathematics and science. Our first set of analyses focuses on more specific content areas. Such analyses will help clarify the strengths and weaknesses of the Minnesota performance.

Fourth grade mathematics

Exhibit 1 presents achievement scores for Minnesota and the TIMSS countries that administered the achievement test for the upper of the two grades containing most 9 year olds, which is fourth grade in the United States. The scores are presented for 14 specific content areas within mathematics. Each country score for an area represents the mean percent of the items in that area that were answered correctly by that countries students.

The countries are listed from the highest scoring to the lowest in each content area. Each area score is divided by shading into three tiers — those countries that scored significantly higher than the US, those who scores were not significantly different from that of the US, and those that were significantly lower than the US.

Minnesota's comparatively best performance was in the area of "geometry: position and shapes" and in "rounding and estimating computations." This was very similar to the

Exhibit 1. Mathematics scores for specific content areas for fourth grade students compared* to the US (national percent correct in each area).

Meaning of Whole Numbers		Whole Number Operations		Common Fractions		Decimal Fractions		Estimating Quantity & Size		Rounding & Estimating Computations		Measurement Units	
Korea	88.1	Korea	82.5	Singapore	71.8	Singapore	83.2	Japan	78.0	Korea	76.8	Japan	76.5
Singapore	81.6	Japan	80.2	Hong Kong	65.3	Korea	75.0	Hong Kong	70.5	Japan	74.8	Korea	72.1
Japan	79.9	Singapore	79.2	Japan	62.5	Hong Kong	72.6	Czech Republic	67.9	Hong Kong	74.8	Netherlands	72.0
Hong Kong	76.4	Hong Kong	76.9	Korea	61.5	Japan	71.3	Hungary	67.3	Singapore	74.3	Czech Republic	68.2
Hungary	74.5	Czech Republic	74.4	Hungary	61.2	Netherlands	47.1	Korea	67.0	**Minnesota**	**73.5**	Hong Kong	67.6
Minnesota	**74.4**	Netherlands	73.2	Netherlands	60.2	USA	46.8	Netherlands	65.9	Netherlands	68.7	Hungary	66.3
Netherlands	73.3	Hungary	71.5	**Minnesota**	**59.6**	International	44.6	Singapore	65.3	Hungary	68.6	Singapore	61.3
Czech Republic	72.9	**Minnesota**	**67.9**	USA	53.7	Australia	43.7	Australia	61.2	Czech Republic	68.1	Australia	60.2
Israel	69.8	USA	67.6	Israel	53.3	Thailand	43.6	Norway	60.6	USA	67.2	Norway	60.0
USA	69.8	Israel	66.3	Australia	52.0	Canada	41.5	International	57.2	Canada	61.6	International	56.8
Australia	68.9	International	64.1	Canada	50.4	Czech Republic	40.1	England	52.2	Israel	61.2	England	52.3
Canada	68.7	Australia	61.5	International	50.0	**Minnesota**	**39.5**	New Zealand	51.9	Australia	59.4	Canada	51.7
International	65.9	Canada	61.5	Czech Republic	49.7	Hungary	36.4	Canada	50.7	International	55.2	Israel	51.0
Norway	61.4	Norway	57.6	England	49.1	Israel	34.2	Israel	50.5	New Zealand	47.9	New Zealand	49.7
New Zealand	59.1	England	53.1	Thailand	46.4	England	32.0	Thailand	49.8	England	47.7	**Minnesota**	**48.7**
England	59.0	Thailand	52.7	New Zealand	45.3	Norway	28.9	USA	47.1	Norway	46.4	USA	48.0
Thailand	57.3	New Zealand	50.8	Norway	39.2	New Zealand	26.3	**Minnesota**	**46.6**	Thailand	39.1	Thailand	43.2

Perimeter, Area, & Volume		Geometry: Position & Shapes		Symmetry, Congruence, & Similarity		Proportionality		Patterns, Relations, & Functions		Equations & Formulas		Data Representation, Probability & Statistics	
Singapore	75.9	Australia	71.9	Singapore	88.9	Singapore	63.7	Korea	85.0	Korea	85.3	Singapore	80.8
Korea	73.5	**Minnesota**	**70.6**	Korea	88.8	Netherlands	62.7	Hong Kong	77.8	Japan	84.3	Korea	79.8
Netherlands	71.0	England	70.6	Hong Kong	85.4	Korea	58.1	Singapore	77.5	Singapore	82.6	Japan	78.3
Hong Kong	70.8	Netherlands	70.3	England	80.9	Japan	57.7	Japan	77.2	Hong Kong	76.9	Hong Kong	75.8
Czech Republic	68.2	Hong Kong	70.1	Australia	79.9	Czech Republic	57.3	Hungary	71.4	Hungary	72.4	Netherlands	75.4
Japan	67.5	Canada	69.4	Japan	79.5	Hungary	55.5	Netherlands	70.4	Netherlands	72.2	**Minnesota**	**74.3**
Hungary	62.8	USA	67.7	**Minnesota**	**79.3**	Hong Kong	53.3	Czech Republic	69.8	Czech Republic	71.0	USA	73.0
Minnesota	**59.9**	Czech Republic	67.4	USA	78.5	Australia	51.3	Australia	69.6	Israel	66.8	Canada	68.0
Canada	59.3	Japan	66.7	Canada	78.5	England	46.6	USA	69.1	USA	65.6	Czech Republic	67.1
International	58.8	Singapore	65.3	Czech Republic	77.8	Israel	46.0	Canada	67.1	International	62.0	Australia	67.1
USA	58.3	New Zealand	65.3	Netherlands	74.1	USA	45.5	International	63.2	Canada	61.4	England	65.8
Israel	57.1	Korea	65.1	Hungary	73.3	International	45.5	Israel	62.6	Australia	60.0	Israel	63.4
England	55.2	Hungary	62.3	International	70.5	**Minnesota**	**45.0**	England	62.0	**Minnesota**	**60.0**	International	61.8
Norway	54.5	International	61.7	New Zealand	69.1	Canada	43.8	**Minnesota**	**60.0**	Thailand	54.0	New Zealand	61.5
New Zealand	49.1	Israel	59.1	Israel	69.0	New Zealand	43.7	New Zealand	57.5	New Zealand	50.5	Hungary	60.3
Thailand	48.2	Norway	58.3	Thailand	66.5	Norway	40.8	Norway	54.7	Norway	49.5	Norway	59.5
		Thailand	47.6	Norway	56.1	Thailand	34.0	Thailand	52.4	England	48.2	Thailand	55.5

* International means are based on all countries participating in the TIMSS assessment at each of the indicated student grade levels. Significant difference categories were determined using standard errors and comparisons among the participating countries. Only the focal countries for this report are included in the exhibits. Therefore, each significant difference category may contain additional countries to those included in the exhibit tables.

KEY
Significantly Higher
No Sig. Difference
Significantly Lower

results for the United States, where geometry was also its best performance area. Minnesota, however, was second in absolute ranking only to Australia, and their performance was not statistically significantly different from that of Australia. In other words, for a basic area of geometry — introducing students to position and shapes — Minnesota students performed in the top tier in the world. In both of these topics — geometry and rounding — the Minnesota performance was statistically significantly higher than that of US students as a whole.

Minnesota's worst performance was in "measurement units" and "estimating quantity and size." This performance mirrors precisely that of US students as a whole, as both were similarly the worst areas of performance for all US students. In both cases, US students were well below the international average with none of the 14 countries reported here ranked below the US. The same is true for Minnesota as well.

In contrasting the performance of Minnesota's students with that of US students as a whole, some interesting differences are noted. Minnesota outperformed the US as a whole in the following areas: "meaning of whole numbers", "common fractions", "rounding and estimating computations", and "geometry: position and shapes." But Minnesota students did not outperform the US in all areas. In several topics their performance was below that of the US as a whole. Those areas are "decimal fractions", "equations and formulas", and "patterns relations and functions." For all other areas not specifically mentioned, Minnesota and US performance were similar.

Minnesota students do better in geometry topics but not in the algebra related topics. For the topic fractions, Minnesota students slightly outperformed those of the US on common fractions but performed lower than the US on decimal fractions. The differences described above are especially interesting given that for the overall test results, statistically speaking, Minnesota and the United States as a whole were indistinguishable. It is clear on examining the sub areas of mathematics that although the total score reflected similar learning patterns for the US and Minnesota, a closer examination finds striking differences in the mathematics profile of what was known by fourth graders in

Minnesota versus that of students in the US as a whole.

Fourth grade science

Exhibit 2 presents comparable data for 15 areas of science for the upper grade of the two grades containing most 9 year olds (fourth grade in the US). No countries outperformed Minnesota in "earth processes", "earth in the universe", "plants and animals", 'organ and tissues", "interactions of living things", "human biology", "environmental resource issues", and "scientific processes." These results parallel that of the US students as a whole in four of the areas: "organs and tissues", "interaction of living things", "human biology", and "scientific processes." The results for Minnesota again prove interesting when compared against the United States, even though the US and Minnesota scores were almost identical for the overall results and were not statistically distinguishable. Minnesota outperformed the United States in "earth features", "earth processes" and "earth in the universe" - all three sub areas defining earth science.

Minnesota students also outperformed the US in the areas of "plants and animals", "organs and tissues", "life cycles and genetics", "interactions with living things", "human biology", "matter", "energy and physical processes", and "physical and chemical changes."

For several of these areas, although the differences are statistically significant, the absolute magnitude of the differences are not large except for the areas of "forces and motion" and "energy and physical processes, where rather large differences exist between the US performance and that of Minnesota. Both of those topic areas are a part of physics.

Eighth grade mathematics

Exhibit 3 presents data similar to that of Exhibit 1 but for the upper of the two grades containing the most 13 year olds (eighth grade in the US), and the 20 topic areas which were included on the test at this level. Minnesota's two strongest content areas at this

Exhibit 2. Science scores for specific content areas for fourth grade students compared to the US (national percent correct in each area).

Earth Features	
Korea	70.9
Minnesota	67.2
Japan	63.3
USA	60.2
England	59.1
Canada	58.4
Czech Republic	57.9
Hungary	57.6
Netherlands	57.3
Norway	56.3
Australia	55.8
New Zealand	54.0
Hong Kong	53.7
International	53.3
Singapore	52.7
Israel	48.4
Thailand	42.5

Earth Processes	
Minnesota	70.0
Korea	66.8
Japan	61.6
USA	60.8
Netherlands	58.3
Australia	55.8
England	55.1
Canada	54.8
Singapore	54.3
Czech Republic	53.8
Hungary	53.4
New Zealand	52.7
Hong Kong	51.5
International	49.7
Israel	47.8
Thailand	44.9
Norway	42.2

Earth in the Universe	
Minnesota	88.2
Czech Republic	75.5
Hong Kong	75.2
Hungary	74.9
Norway	74.7
Korea	73.8
Australia	72.3
Canada	70.7
England	70.5
USA	70.5
Netherlands	68.7
Japan	68.7
Singapore	68.6
International	66.8
New Zealand	66.3
Thailand	60.8
Israel	58.2

Plants & Animals	
Minnesota	88.6
Korea	81.4
Japan	78.0
Australia	72.4
Czech Republic	72.2
Singapore	70.4
USA	69.6
Netherlands	67.5
Canada	67.3
England	67.1
New Zealand	66.8
Hungary	65.9
Hong Kong	64.7
International	63.6
Norway	59.9
Thailand	56.5
Israel	55.0

Organs & Tissues	
Minnesota	69.6
Singapore	66.6
Australia	66.4
Czech Republic	65.3
USA	65.0
Hong Kong	64.6
Korea	63.4
Japan	62.9
England	61.6
Canada	61.4
Hungary	61.1
New Zealand	60.8
Netherlands	60.8
Norway	60.5
International	58.9
Israel	56.7
Thailand	55.0

Life Processes & Functions	
Korea	75.5
Japan	75.0
Netherlands	74.0
Australia	69.9
Czech Republic	69.4
Minnesota	69.2
England	69.0
Singapore	68.5
USA	68.2
Norway	67.2
Israel	66.8
Canada	66.4
Hong Kong	65.6
Hungary	64.3
International	64.3
New Zealand	62.7
Thailand	47.8

Life Cycles & Genetics	
Netherlands	76.8
Korea	75.4
Czech Republic	73.1
Minnesota	72.1
Australia	71.3
Japan	71.2
USA	69.7
Canada	68.6
Norway	68.4
England	67.8
Hong Kong	67.8
Hungary	67.5
Singapore	67.3
New Zealand	66.1
International	63.9
Israel	61.7
Thailand	53.1

Interactions of Living Things	
Minnesota	91.9
Netherlands	83.9
USA	82.5
Australia	82.0
Korea	82.0
Japan	78.9
Canada	77.1
Norway	76.4
England	76.1
Czech Republic	75.1
Israel	75.1
Singapore	75.0
New Zealand	74.3
Hong Kong	73.9
International	71.6
Hungary	66.0
Thailand	52.9

Human Biology & Health	
Minnesota	74.7
Netherlands	71.8
Korea	70.4
Australia	70.2
USA	69.3
Norway	68.4
Singapore	67.5
England	67.0
Hong Kong	67.0
Canada	66.4
Czech Republic	66.2
Japan	66.1
Hungary	65.0
New Zealand	63.5
International	63.2
Israel	62.2
Thailand	52.1

Matter	
Korea	77.3
Japan	75.4
Netherlands	67.7
Singapore	66.9
Minnesota	66.1
Australia	62.6
USA	61.5
Canada	61.0
Czech Republic	60.7
Hong Kong	60.3
Hungary	59.1
England	58.0
International	57.8
New Zealand	57.6
Norway	56.0
Israel	52.9
Thailand	46.4

Energy & Physical Processes	
Korea	72.9
Japan	70.1
Minnesota	66.1
Australia	62.6
Netherlands	62.1
England	61.5
Canada	61.1
Czech Republic	61.1
USA	60.7
Singapore	60.7
Hong Kong	59.0
Israel	57.9
Hungary	57.2
International	56.3
New Zealand	55.5
Norway	52.7
Thailand	43.9

Physical & Chemical Changes	
Netherlands	73.7
Korea	72.1
Japan	71.7
Minnesota	69.1
Hong Kong	67.6
Czech Republic	67.1
USA	64.7
Singapore	64.7
Australia	63.5
Canada	61.8
England	60.6
Hungary	59.9
International	59.5
Norway	58.2
Israel	57.5
New Zealand	56.6
Thailand	46.2

Forces & Motion	
Korea	68.3
Japan	62.5
Czech Republic	61.6
Netherlands	61.3
Singapore	59.5
Minnesota	58.7
Norway	57.6
Canada	55.5
Australia	55.4
Hungary	54.6
Hong Kong	54.5
USA	52.6
New Zealand	51.8
International	50.9
England	48.7
Thailand	46.9
Israel	45.8

Environmental & Resource Issues	
Minnesota	79.1
Korea	74.0
Japan	71.6
Australia	69.1
USA	68.0
Netherlands	65.0
Czech Republic	62.7
Hungary	62.0
Canada	60.9
England	59.8
New Zealand	58.7
International	58.2
Norway	58.2
Israel	58.0
Singapore	57.2
Hong Kong	53.8
Thailand	53.4

Scientific Processes	
Minnesota	67.2
Korea	65.7
USA	63.1
Australia	59.4
Singapore	54.3
England	54.1
Japan	53.3
Netherlands	52.0
New Zealand	51.7
Hong Kong	51.4
Czech Republic	51.1
Canada	50.9
Israel	49.8
Norway	48.1
International	45.6
Hungary	40.3
Thailand	40.0

KEY
Significantly Higher
No Sig. Difference
Significantly Lower

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Exhibit 3. Mathematics scores for specific content areas for eighth grade students compared to the US (national percent correct in each area).

Whole Numbers	
Singapore	80.4
Japan	72.0
Switzerland	70.2
Belgium (Fl)	68.6
Korea	67.6
Czech Republic	67.4
Hong Kong	65.4
France	64.5
Russian Federation	62.7
Spain	60.8
Hungary	60.6
Sweden	58.9
Canada	57.9
Israel	59.0
Thailand	56.0
Minnesota	55.5
International	55.5
Germany	55.4
Australia	55.0
Netherlands	53.5
Norway	53.4
USA	52.3
New Zealand	48.6
England	46.8

Common Fractions	
Singapore	82.4
Japan	72.2
Korea	69.9
Hong Kong	69.4
Belgium (Fl)	68.7
Switzerland	62.4
Czech Republic	59.6
Netherlands	58.9
France	57.8
Hungary	57.7
Israel	57.4
Canada	56.2
Russian Federatio	55.8
Australia	55.4
Minnesota	54.9
Thailand	54.2
Sweden	53.1
International	52.1
Germany	51.7
New Zealand	51.5
Norway	51.2
USA	49.3
England	49.2
Spain	49.2

Decimal Fractions & Percents	
Singapore	77.9
Czech Republic	72.5
Hong Kong	71.1
Japan	69.8
Hungary	68.7
Korea	68.4
Russian Federation	65.9
France	64.9
Belgium (Fl)	64.6
Switzerland	61.9
Canada	61.0
Minnesota	59.5
Sweden	59.2
Thailand	58.0
Netherlands	57.8
Germany	57.2
Israel	56.3
USA	55.8
International	55.4
Norway	54.1
Australia	53.5
Spain	50.6
New Zealand	49.3
England	45.9

Relations of Fractions	
Singapore	85.1
Korea	77.6
Japan	75.3
Hong Kong	74.1
Belgium (Fl)	71.3
Switzerland	70.0
France	67.2
Minnesota	66.2
Canada	65.1
Czech Republic	64.9
Germany	62.6
Netherlands	62.5
Sweden	62.2
Australia	61.0
Hungary	60.7
Thailand	59.6
Norway	59.6
Russian Federation	59.2
USA	58.5
Israel	57.6
International	56.9
New Zealand	56.8
England	53.8
Spain	48.2

Estimating Quantity & Size	
Japan	77.9
Singapore	77.3
England	72.2
Hong Kong	71.8
Switzerland	71.8
Czech Republic	71.7
Netherlands	71.2
Belgium (Fl)	70.7
Korea	70.7
Minnesota	69.6
Australia	69.3
Hungary	69.3
Sweden	69.3
France	69.0
Germany	69.0
Canada	67.8
Norway	66.6
New Zealand	65.3
Russian Federation	63.5
USA	62.7
International	61.0
Israel	58.4
Thailand	57.1
Spain	54.8

Rounding	
Czech Republic	86.9
Singapore	86.6
Canada	84.7
Korea	83.8
Minnesota	82.6
Belgium (Fl)	81.0
Hungary	79.8
Japan	79.6
USA	79.2
Netherlands	78.5
Sweden	78.5
Australia	77.5
Switzerland	77.4
Thailand	75.4
France	74.7
New Zealand	74.4
Hong Kong	74.2
England	74.2
Russian Federation	73.5
Norway	72.3
International	70.7
Germany	69.9
Israel	68.8
Spain	62.2

Estimating Computations	
Singapore	75.8
Czech Republic	69.8
Japan	69.0
Korea	66.7
Belgium (Fl)	64.1
Switzerland	62.5
Canada	61.3
Sweden	60.0
Australia	59.1
Netherlands	58.7
Minnesota	58.1
Hong Kong	57.8
New Zealand	57.6
Hungary	57.3
Norway	57.0
USA	55.7
England	54.4
Germany	52.0
Israel	51.9
France	50.8
International	50.6
Russian Federation	50.0
Thailand	49.5
Spain	44.1

Measurement Units	
Singapore	77.9
Japan	74.8
Czech Republic	73.2
Belgium (Fl)	71.8
Switzerland	71.6
Sweden	69.5
France	69.0
Korea	67.9
Hungary	67.5
Netherlands	66.8
Norway	66.4
Russian Federation	65.9
Hong Kong	65.2
Australia	65.0
Germany	63.5
Canada	63.0
Israel	63.0
Spain	62.4
Thailand	62.3
International	61.3
New Zealand	61.3
Minnesota	60.7
England	60.5
USA	53.0

Perimeter, Area, & Volume	
Singapore	84.5
Japan	72.6
Hong Kong	63.9
Korea	61.8
Czech Republic	48.9
Switzerland	46.6
Belgium (Fl)	45.6
Russian Federation	44.6
France	44.1
Netherlands	44.0
Hungary	42.9
Australia	42.1
Canada	40.4
Thailand	40.0
Sweden	39.3
International	39.0
England	37.1
Israel	36.9
Norway	36.4
New Zealand	35.0
Minnesota	33.7
Germany	32.9
Spain	29.9
USA	27.8

Measurement Estimation & Errors	
Czech Republic	82.9
Singapore	81.0
Sweden	80.8
Korea	79.5
Belgium (Fl)	78.9
Hungary	78.2
Switzerland	78.2
Netherlands	76.1
France	75.2
Australia	74.5
Norway	74.5
Germany	72.9
Hong Kong	72.7
Japan	72.5
Minnesota	71.8
England	71.8
New Zealand	70.6
Canada	69.7
Russian Federation	69.6
Thailand	66.1
International	64.7
Israel	63.3
USA	62.5
Spain	55.3

2-D Geometry	
Japan	78.9
Singapore	78.3
Korea	75.5
Hong Kong	73.5
Russian Federation	63.4
Netherlands	62.9
Thailand	62.4
Czech Republic	62.1
Hungary	61.6
Australia	58.8
Belgium (Fl)	58.8
Switzerland	57.9
France	56.1
New Zealand	55.8
Minnesota	55.7
England	54.9
Canada	54.7
International	53.8
Israel	52.5
Norway	52.1
Spain	49.5
Germany	49.3
USA	47.9
Sweden	46.1

Polygons & Circles	
Korea	73.0
Japan	70.8
Singapore	70.6
Hong Kong	65.4
Belgium (Fl)	64.1
France	61.9
Israel	59.7
Czech Republic	57.4
Russian Federation	57.2
Thailand	53.5
Hungary	51.6
Canada	50.5
Australia	50.4
International	48.9
Switzerland	48.6
England	47.0
Germany	44.3
Netherlands	44.0
New Zealand	43.2
Minnesota	43.2
Sweden	42.8
Norway	42.4
Spain	39.3
USA	39.1

3-D Geometry & Transformations	
Japan	84.3
Singapore	78.6
Czech Republic	77.7
France	77.7
Hong Kong	77.6
Switzerland	75.9
Belgium (Fl)	73.7
Korea	73.3
Hungary	71.0
Netherlands	70.6
Russian Federation	70.2
Canada	70.1
New Zealand	67.3
England	66.3
Australia	65.5
Minnesota	65.4
Israel	64.8
Thailand	64.5
Germany	63.7
International	33.4
Norway	58.6
USA	58.4
Spain	58.2
Sweden	55.9

Congruence & Similarity	
Japan	79.7
Korea	76.9
Singapore	76.7
Hong Kong	71.0
France	69.7
Czech Republic	66.1
Thailand	62.7
Russian Federation	62.3
Belgium (Fl)	57.5
Israel	54.8
Hungary	53.4
Canada	52.8
International	52.6
Switzerland	51.2
Netherlands	51.0
Australia	50.9
Norway	46.9
Minnesota	46.7
New Zealand	45.9
Sweden	45.9
England	45.6
Germany	45.1
USA	44.1
Spain	43.6

Proportionality Concepts	
Singapore	70.1
Korea	57.0
Japan	56.9
Hong Kong	50.1
Netherlands	41.9
Canada	40.3
Sweden	39.2
Belgium (Fl)	39.0
Australia	37.8
Czech Republic	37.3
France	37.3
Switzerland	36.8
Thailand	36.5
England	34.8
Minnesota	34.7
Hungary	34.6
Russian Federation	33.5
International	33.4
New Zealand	33.4
USA	31.5
Israel	31.4
Norway	30.9
Spain	27.4
Germany	26.5

Proportionality Problems	
Singapore	76.7
Japan	67.8
Korea	65.1
Hong Kong	64.0
Czech Republic	61.3
Belgium (Fl)	59.4
Switzerland	57.3
Russian Federatio	56.3
Thailand	56.0
Hungary	55.9
Netherlands	55.9
France	55.7
Australia	52.2
Canada	51.6
International	50.1
Minnesota	49.3
Sweden	49.2
Germany	49.0
England	47.2
New Zealand	47.1
Norway	47.1
Israel	46.5
USA	45.2
Spain	43.6

Patterns, Relations & Functions	
Japan	70.0
Korea	68.4
Singapore	67.2
Hong Kong	60.8
Czech Republic	60.2
England	60.1
Switzerland	59.5
Belgium (Fl)	59.2
Hungary	59.1
Canada	58.2
Australia	57.6
Netherlands	56.9
Minnesota	56.2
New Zealand	55.7
France	55.0
Thailand	53.4
Russian Federation	53.2
Israel	53.2
International	51.4
USA	51.1
Spain	50.3
Norway	48.7
Germany	47.6
Sweden	47.2

Equations & Formulas	
Singapore	79.8
Minnesota	77.6
Japan	72.3
Hong Kong	70.5
Korea	70.0
Czech Republic	64.3
Belgium (Fl)	62.1
Russian Federation	61.4
Hungary	60.9
Israel	58.3
Thailand	54.0
France	53.6
Australia	52.8
Canada	52.4
Spain	52.2
Switzerland	51.9
Netherlands	51.7
USA	49.4
International	49.4
New Zealand	46.6
Germany	46.4
Norway	44.9
England	44.1
Sweden	43.7

Data Representation & Analysis	
Japan	84.3
Korea	81.9
France	81.4
Switzerland	81.3
Singapore	81.0
Netherlands	80.6
Czech Republic	79.6
Sweden	79.5
Belgium (Fl)	79.5
Minnesota	77.6
Hong Kong	76.4
Germany	76.0
Norway	75.5
Australia	75.2
Canada	75.0
England	74.8
Thailand	74.5
New Zealand	74.1
Hungary	73.7
Israel	73.2
USA	72.6
Russian Federation	72.0
International	70.9
Spain	70.4

Uncertainty & Probability	
Singapore	78.5
Korea	77.8
Belgium (Fl)	77.7
Japan	75.0
Hong Kong	73.0
Netherlands	72.4
Switzerland	72.4
Canada	70.0
Sweden	68.7
Australia	67.5
France	66.5
Hungary	66.2
New Zealand	65.9
England	65.3
Norway	64.7
Czech Republic	63.4
USA	63.1
Germany	62.4
Israel	62.3
Minnesota	60.9
International	59.6
Spain	58.0
Russian Federation	56.9
Thailand	56.5

KEY
Significantly Higher
No Sig. Difference
Significantly Lower

45

44

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level were 'rounding" (which was also the case for the US as a whole) and "equations and formulas" (which was not the case for the US as a whole).
In fact, Minnesota's performance in the areas of the equations and formulas was only slightly behind that of the top achieving country in this area, Singapore. By contrast, the performance of US students in this area was such that they only outperformed England and Sweden.

In many areas Minnesota's performance mirrored that of the US as a whole with only a few exceptions other than those noted above. In the following areas Minnesota outperformed the United States: "estimating quantity and size", "measurement estimation and errors", "2-D and 3-D geometry", and "data representation and analysis."

It is particularly interesting to note that the Minnesota's performance in "equations and formulas" at fourth grade was among their worst, but at the end of eighth grade this was the strongest area of performance and ranked strongly against all other nations.

Eighth grade science

Exhibit 4 presents science data for eighth grade, the upper of the two grades with the most 13 year olds — this is similar to the fourth grade science data in Exhibit 2. Data are presented for 17 content areas. Since the US's overall science score standing was high at fourth grade and around average at eighth grade and since Minnesota's overall science score standing was similarly high at fourth grade and at eighth grade, we might expect a set of major differences in the scores when we compare Minnesota with the US as a whole.

In "earth processes" and "earth in the universe," Minnesota was not outperformed statistically by any other nation. Their correspondingly strong performance in the area of "earth features" provides strong evidence as to a very high international ranking in the area of earth sciences, a finding noted in the earlier Minnesota reports. These results, however, go further and suggest that "earth processes" and "earth in the universe" are the two sub areas where Minnesota has stronger performance than in the sub area of "earth

Exhibit 4. Science scores for specific content areas for eighth grade students in selected countries compared to the US mean (national percent correct in each area).

Earth Features	
Czech Republic	67.1
Hungary	67.1
Korea	65.3
Singapore	64.6
Minnesota	64.3
Belgium (Fl)	61.1
Sweden	60.5
Thailand	59.7
Russian Federation	59.2
Norway	59.2
Japan	59.0
England	58.7
Switzerland	58.2
Netherlands	58.0
Australia	57.5
Germany	57.2
USA	57.1
Canada	56.6
Israel	56.1
Spain	55.9
New Zealand	55.9
International	55.4
France	55.1
Hong Kong	54.1

Earth Processes	
Minnesota	66.8
England	66.7
Singapore	66.7
Belgium (Fl)	65.4
Netherlands	62.5
Norway	62.3
USA	60.9
Russian Federation	60.8
Canada	60.6
Sweden	60.0
Korea	59.0
Japan	58.5
New Zealand	57.3
Czech Republic	57.2
Australia	56.7
Thailand	56.0
Switzerland	56.0
Spain	55.5
France	55.0
Israel	54.7
Germany	53.9
International	53.5
Hong Kong	52.3
Hungary	51.3

Earth in the Universe	
Minnesota	73.8
Sweden	70.7
Norway	70.1
Netherlands	67.5
Czech Republic	66.9
Japan	66.7
Thailand	66.0
Singapore	64.9
Switzerland	64.8
Korea	64.4
USA	63.3
Germany	62.8
Spain	62.8
Australia	62.7
Belgium (Fl)	61.8
New Zealand	61.7
Canada	61.2
England	59.0
Hungary	58.5
International	58.2
Hong Kong	58.0
Israel	56.2
Russian Federation	56.9
France	53.2

Diversity & Structure of Living Things	
Japan	75.9
Singapore	74.2
Hong Kong	73.4
Korea	72.5
Czech Republic	72.3
Netherlands	71.6
Minnesota	70.2
Thailand	68.8
Sweden	67.7
Hungary	67.1
Australia	66.7
Germany	65.7
Russian Federation	65.7
England	64.5
USA	63.9
Canada	63.3
Belgium (Fl)	62.9
New Zealand	62.3
Spain	61.3
International	61.3
Switzerland	61.0
Israel	60.4
Norway	59.2
France	58.4

Life Processes & Functions	
Singapore	72.3
Japan	70.4
Korea	68.2
Czech Republic	63.7
Thailand	63.0
Belgium (Fl)	62.9
Minnesota	62.9
Netherlands	60.7
Hungary	59.9
Russian Federation	59.4
England	59.3
Germany	58.1
USA	58.0
Australia	57.4
Canada	57.2
Israel	57.1
Hong Kong	56.3
New Zealand	56.1
Spain	55.9
Sweden	54.9
International	54.5
Switzerland	54.2
Norway	54.2
France	53.8

Life Cycles & Genetics	
Minnesota	85.7
Czech Republic	81.8
USA	81.2
England	80.4
Netherlands	79.3
Israel	79.0
Belgium (Fl)	78.9
Canada	78.4
Sweden	78.2
Norway	78.1
Korea	75.9
France	75.7
Russian Federation	75.5
Germany	75.5
Switzerland	75.1
Japan	74.8
New Zealand	73.9
Hungary	73.7
Australia	73.0
Spain	71.1
International	70.2
Singapore	68.6
Thailand	67.3
Hong Kong	65.3

Interactions of Living Things	
Korea	68.8
Singapore	65.6
Minnesota	65.4
Japan	65.0
Thailand	64.1
Hungary	63.1
Australia	62.0
England	61.5
Norway	59.9
Canada	58.2
Czech Republic	57.6
New Zealand	55.9
Netherlands	55.8
USA	54.3
Germany	52.9
Belgium (Fl)	52.9
Spain	52.9
Russian Federation	52.3
Sweden	52.1
International	51.0
Israel	50.2
Switzerland	49.8
Hong Kong	46.6
France	44.8

Human Biology & Health	
Singapore	74.0
Czech Republic	71.6
Netherlands	71.2
Minnesota	70.5
Japan	69.4
Belgium (Fl)	69.3
Hungary	68.7
England	68.3
Israel	67.6
Germany	67.6
USA	66.8
Thailand	66.5
Australia	66.5
Korea	65.5
Canada	65.3
Sweden	63.9
New Zealand	63.7
Spain	63.2
Russian Federation	63.1
Norway	62.6
Switzerland	61.4
International	61.2
Hong Kong	59.9
France	55.7

Properties & Classification of Matter	
Japan	66.6
Singapore	66.6
Korea	65.4
Czech Republic	60.4
Netherlands	58.3
Belgium (Fl)	57.9
Hungary	57.3
Sweden	57.2
Hong Kong	56.4
Canada	55.7
Norway	54.8
Australia	54.7
England	54.7
Germany	54.9
Russian Federation	54.3
New Zealand	53.5
Israel	53.5
Minnesota	52.4
France	52.3
International	51.6
Switzerland	51.1
USA	49.9
Spain	49.6
Thailand	46.7

Structure of Matter	
Russian Federatio	56.4
Hungary	53.9
Czech Republic	54.2
Singapore	53.2
Spain	51.0
Minnesota	49.1
USA	48.2
Israel	44.7
Sweden	42.7
Korea	42.1
Japan	41.1
Hong Kong	40.0
International	39.6
Australia	38.7
England	38.1
Canada	37.1
Germany	35.2
New Zealand	34.5
Norway	31.9
Thailand	30.6
Netherlands	30.0
France	29.4
Switzerland	28.6
Belgium (Fl)	27.4

Energy & Physical Processes	
Singapore	71.2
Japan	68.8
Korea	67.2
England	64.1
Netherlands	63.8
Minnesota	62.8
Czech Republic	62.3
Belgium (Fl)	62.2
Australia	61.1
Hungary	60.2
New Zealand	59.9
Canada	59.9
Hong Kong	59.5
Israel	59.5
Germany	59.3
Switzerland	58.7
Russian Federation	58.4
USA	57.1
Norway	56.6
Sweden	56.6
International	56.4
Thailand	55.3
Spain	55.2
France	54.6

Physical Changes	
Japan	66.7
Singapore	63.1
Czech Republic	62.9
France	61.9
Israel	61.4
Sweden	61.3
Netherlands	61.1
Hungary	61.0
Norway	60.0
England	58.9
Belgium (Fl)	58.7
Canada	58.5
Korea	57.3
Australia	57.1
Russian Federation	57.0
Switzerland	54.0
Germany	53.6
Thailand	53.2
Spain	53.1
International	52.8
New Zealand	52.8
Minnesota	50.3
USA	49.1
Hong Kong	48.8

Chemical Changes	
Singapore	73.5
Korea	65.9
Hungary	65.4
Minnesota	65.1
Czech Republic	64.2
England	63.7
Japan	63.5
Australia	61.9
Russian Federation	61.8
USA	61.4
Germany	60.7
Israel	60.6
Canada	59.6
New Zealand	59.4
Hong Kong	58.2
Spain	58.1
Netherlands	57.6
Sweden	57.1
International	56.5
Belgium (Fl)	55.6
Switzerland	55.4
Norway	53.4
France	52.5
Thailand	50.9

Forces & Motion	
Czech Republic	78.1
Japan	73.6
Singapore	73.4
Netherlands	71.2
Korea	69.6
Hong Kong	69.4
Switzerland	68.8
Hungary	68.7
England	67.6
Sweden	67.5
Australia	67.2
Norway	67.1
Canada	66.3
Germany	66.9
New Zealand	65.6
Belgium (Fl)	65.2
France	63.8
Minnesota	63.4
Spain	62.6
Russian Federation	62.1
USA	61.3
International	61.2
Israel	54.9
Thailand	56.4

Science, Technology, & Society	
Korea	74.3
Hungary	73.3
Netherlands	67.4
Sweden	66.9
Singapore	66.4
Belgium (Fl)	65.2
New Zealand	60.4
Japan	60.1
Thailand	59.2
England	57.2
Hong Kong	54.8
Canada	52.5
Switzerland	52.5
Norway	52.1
Czech Republic	51.9
Minnesota	51.9
Australia	51.5
Israel	51.3
International	47.9
USA	47.5
Germany	47.3
Spain	44.1
France	42.9
Russian Federation	40.4

Environmental & Resource Issues	
Singapore	73.1
Thailand	70.1
Minnesota	67.7
England	67.2
Netherlands	65.1
Australia	64.7
Korea	62.7
Japan	61.7
Canada	61.5
New Zealand	61.4
USA	59.9
Belgium (Fl)	59.7
Czech Republic	59.1
Spain	58.6
Norway	58.2
Hong Kong	53.3
International	53.0
Sweden	51.8
Israel	51.6
Switzerland	50.3
Germany	50.1
Hungary	49.4
France	48.5
Russian Federation	46.8

Scientific Processes	
Singapore	74.6
Netherlands	65.2
Korea	64.2
Minnesota	63.0
France	62.2
Czech Republic	60.7
Australia	60.6
Japan	60.1
England	60.0
Canada	59.2
USA	58.9
Hungary	57.3
Hong Kong	57.2
Belgium (Fl)	56.9
New Zealand	56.7
Thailand	55.3
Germany	53.4
Switzerland	53.3
International	53.1
Sweden	52.4
Norway	52.1
Israel	51.8
Russian Federation	51.2
Spain	49.6

KEY
Significantly Higher
No Sig. Difference
Significantly Lower

U.S. TIMSS National Reserach Center, Michigan State University features."

In addition, Minnesota also achieved the highest score among all nations in the areas of "life cycles and genetics." Here, the US also performed extremely well, and the US's score is not statistically significantly different from that of Minnesota.

Minnesota outperformed the US as a whole not only in earth sciences, "life cycles and genetics" but also in "diversity and structure of living things", and the "interactions of living things."

For topics in physics and chemistry, Minnesota only outperformed the United States in "energy and physical processes," where they were only outperformed by Singapore, Japan, Korea, England and the Netherlands. Minnesota also outperformed the US in the areas of "environmental resource issues" where their scores ranked among the top scores in the world.

General conclusions about topic areas

The fourth and eighth grade Minnesota performance varied depending on the specific content area, and Minnesota performance also varied from the United States in different content areas in math and science at the different grade levels. Even in those areas where Minnesota's performance on the total score was similar to that of the US as a whole, an examination of the separate content areas reflects very different profiles of what students know.

This raises an important policy issue. Concern about weak or strong performance in a content area for the US as a whole might not be appropriate for specific states and is clearly not appropriate for the state of Minnesota. Students in Minnesota obviously have learned different areas of science better than their counterparts in the rest of the US. They also have weaknesses in certain other areas, and in many other areas their learning pattern is similar to the US as a whole.

Policy implications with respect to curriculum for the state of Minnesota would have to clearly take into account the particular profile reflected in the above results for the state as a whole, especially when those results are not consistent with the US as a whole. The policy implications associated with Minnesota's stronger performance in science at eighth grade and in both math and science at the end of twelfth grade again suggest the subtlety of adopting state policies consistent with the national thrust but reflecting the specific results of TIMSS.

Assessing The Achievement Gains Of Minnesota Students

One of the strengths of the TIMSS design is that while a true longitudinal data collection for a school year was not possible given other goals of the study, the possibility of quasi-longitudinal analyses were built into the design. Students were tested in the two adjacent grades that contained the most nine-year-olds and in the two that contained the most 13-year-olds. The samples were larger in some countries for the upper of the two grades but were sufficiently large at the lower grade to allow national achievement estimates at both.

This yields pairs of achievement estimates approximately one grade apart. These can be treated at least as quasi-longitudinal, as long as we realize that we are not tracking precisely the same students and if we make a few assumptions. First, we must assume that there were no major cohort differences between those in pairs of grades. Sampling was designed to make cohorts at both grades at each pair nationally representative of the students of that grade level. This was also true for students in the state of Minnesota. This makes it unlikely that significant cohort differences exist. Second, we must ignore retention differences among countries over the two grades, since students who are not retained might have differed significantly than those who were in how they achieved. This is, however, not a significant problem in the US or in Minnesota or for that matter in most other countries, because both nine and 13 year olds were below the age that mandatory schooling ended. With these assumptions we can treat the grade pairs as allowing a longitudinal-like analysis of achievement gains.

In most of the samples, especially in the United States, the adjacent grades were in the same school, which makes even more reasonable the assumption that their comparison represents a grade's gain. The focus in the US is on grades three and four and on grades seven and eight. These students were tested near the end of the school year and had most of their grade's experience and access to learning possibilities. The difference between estimated national achievements at the lower and the upper of the two grades could be assumed, given the other assumptions above, to be attributable to the effects of schooling at the upper grade. Measures of achievement gains at the national level could thus be linked to aggregate national curriculum and educational system characteristics. It is hoped that this would also be possible for a state such as Minnesota.

These quasi-longitudinal possibilities allowed us to focus on what US and Minnesota students learned at both fourth and eighth grades. For the US as a whole, the answer was that little new was mastered in either of those two grades. For Minnesota the answer was different. In mathematics and at fourth grade in science the answer was similar to that given for the US as a whole, but for science at eighth grade the story was quite different and revealing.

Mathematics

The US results at both fourth and eighth grade demonstrated relatively small gains in all areas of the curriculum. This led other reports and us to characterize the gain pattern for the United States as reflecting a curriculum that is "a mile wide and an inch deep." The results for Minnesota at both fourth and eighth grade are very similar to that of the US as a whole with some notable exceptions. Unfortunately, Minnesota's pattern of gains is consistent with the US in most areas in exhibiting very small gains.

In several of the areas, however, the gain of Minnesota's students is appreciably lower than that of the US as a whole. The areas in which this was especially the case were "decimal fractions", "perimeter area volume", "congruence and similarity", "equations and formulas", and "data analysis." Given the relatively strong performance of Minnesota fourth graders as reported in an earlier section, the analysis here may well reflect that most of what was assessed on the TIMSS test at fourth grade, students may have learned during the first three years of school with not much additional learning during the fourth grade.

This would be true if the curriculum (to be discussed in a later section) did not incorporate much new material during the fourth grade — at least new material that was reflected on the TIMSS test.

The one area that is particularly interesting is "decimal fractions." The amount of learning or gain from third to fourth grade for Minnesota students place them last in the international rankings. The US as a whole ranked high in terms of gain for this content area. The low ranking in terms of gain together with the low status of Minnesota students at fourth grade, as reflected in Exhibit 1, suggest a topic that should be looked at more carefully with respect to the Minnesota curriculum. This will be discussed in a subsequent section.

The pattern at eighth grade for Minnesota is also very similar to that of the United States as a whole. The highest rankings for the US were in the areas of "data representation and analysis" and "estimating quantity and size." This was not the pattern for Minnesota. In Minnesota, the largest gains in terms of international rankings were in the areas of "measurement estimation and errors", "functions", and "measurement units." The gain at eighth grade in the area of "measurement estimation and errors" in fact placed Minnesota in the top five countries. For most of the other content areas Minnesota's pattern was consistent with that of the US as a whole.

Science

For the US as a whole the pattern of gains in the content areas of science was very similar to that for mathematics. The US pattern reflects small gains in almost all areas as opposed to relatively large gains in some content areas at certain grades with attendant small gains in other content areas. The US gains in science barely placed them high in the international rankings. In fact, for most content areas their ranking was in the lower part of the distribution.

At fourth grade, the Minnesota pattern is very similar to that of the US as a whole. No particular content areas stood out in terms of reflecting large gains nor for that matter were the Minnesota pattern of gains distinct in any significant way from that of the US as a whole. Again, this may well reflect, given the relatively strong performance of Minnesota fourth graders on the overall TIMSS test, that much of what was known in science as reflected in the TIMSS test was learned in the earlier grades without much additional learning taking place during the fourth grade.

A pattern of achievement gains in eighth grade science for Minnesota was remarkably different from that of the US. The US pattern at eighth grade, like that at fourth grade was small gains in almost all content areas. Minnesota's achievement gains reflected the pattern observed in other countries with peaks and valleys.

In some areas, Minnesota's gain (reflecting the amount of learning taking place during eighth grade) was relatively large and placed them at or near the top of the international rankings. For other areas the gains observed for Minnesota placed them at or near the very bottom of the international rankings. Several distinct patterns are discernable for the Minnesota data.

Minnesota had large gains from seventh to eighth grade in the following areas: "earth features", "earth in the universe", "environmental and resource issues", and "chemical changes." The gain of Minnesota students in "earth processes" was also relatively large but did not place them in the top tier of countries.

One common thread that is reflected across the content areas of the curriculum in which Minnesota students had their strongest international rankings in terms of gain is that all of these topic areas could be a part of a formal course in earth science. For the topics "earth features", "earth processes", "earth and the universe", and "environmental and resource issues" this inference seems relatively straightforward.

However, for "chemical changes" the linkage to earth science may not seem as obvious until one is reminded that much of earth science involves an understanding of the chemical changes that take place during the water cycle, and the tectonic cycle and involves an analysis of the minerals and rocks contained in the geological structures of the earth.

In contrast to the United States as a whole, Minnesota actually achieved gains that would place them in the top twenty-five percent of countries at the eighth grade in certain of these content areas. This was not accomplished by US students as a whole in any area of science at either fourth or eighth grade.

This pattern of strong gains in certain content areas was offset by relatively small gains in several other content areas. Among the content areas reflecting such relatively small gains by international standards are "diversity and structure of living things", "life processes and functions", "life cycles and genetics", and "human biology." The common thread to these content areas is they are all a part of biology.

The other content areas in which Minnesota ranked near the bottom of the international distribution are: "physical changes", "energy and physical processes", "forces in motion", "the properties and classification of the matter" — all topics related to physics.

The meaning of the relatively small gains in the biology and physics topics might well have different interpretations when one considers the results presented in Exhibit 4. In several of the biology areas, especially in 'life cycles and genetics', Minnesota performed very well on the status measure at the end of eighth grade. The small gains discussed in this section may well reflect that students for the most part had acquired this knowledge before eighth grade and simply retained it. When tested at the end of eighth grade, their performance placed them very high among other countries.

On the other hand, the relatively small gains noted for the various areas of physics coupled with the fact that in Exhibit 4 Minnesota students did not do very well on these physics topics would likely imply that they did not receive much instruction on these topics either before or during eighth grade.

By contrast the relatively strong showing of Minnesota on the "earth features", "earth processes" and "earth in the universe" subtests (as found in Exhibit 4) coupled together with the strong gains discussed in this section suggest that much of the learning in these content areas took place during eighth grade.

Overall conclusions

One could argue that an effective curriculum should produce major gains in at least some content area at each grade. Even if students did well in many areas because of cumulative gains over several years it seems likely that there would be major gains at some grade level for at least one content area. This would seem to be particularly true if the curriculum had different content areas that received focus and instructional attention at different grade levels. This, as we have argued elsewhere, appears to be the case for almost all of the TIMSS countries. This also seems to be the case for Minnesota in science at eighth grade, where the pattern of peaks and valleys reflective of other countries achievement gain patterns is present in marked contrast to that of the US as a whole.

Only a curriculum that was composed largely without such focused attention would consistently produce, at best, modest gains across the content areas. However, this is exactly the pattern that is true for the US as a whole in both science and mathematics at fourth and eighth grades. This is also true for Minnesota in mathematics at both fourth and eighth grades as well as for science at fourth grade.

As reported elsewhere, this distinction is reinforced by the fact that of the 26 countries who tested both 9 and 13 year olds the US was the only country not a part of the top gaining countries in science or mathematics in either fourth or eighth grade for any content area (except the "scientific processes" area).

This conclusion for the US as a whole also holds for Minnesota in mathematics but not in science. Minnesota is thus different than the US as a whole by actually becoming a part of the top gaining countries in at least some area of science at the eighth grade. Those areas include "earth features", "earth and the universe", "chemical changes" and "environmental and resource issues" — topics typically considered a part of earth science.

What Content Is Taught In Minnesota Schools?

The specific content areas and topics of mathematics and science that we choose to teach largely determine the learning opportunities for students. What we ask them to do with these topics is another important determinate.

The specifications of the topics to be covered in the curriculum at each grade level are found in national content standards for most of the countries participating in TIMSS. A few of the nations, whose constitutional authority regarding education allows less control at the national level, have regional specifications of content standards that guide instruction in the schools within those jurisdictions.

As discussed elsewhere in "Splintered Vision" the US system is quite different in that control of education rests both at the state and local level. National statements of content that is desirable to be taught in US schools is usually done through professional associations such as the National Council of Teachers of Mathematics (NCTM), American Association for the Advancement of Science (AAAS) or the National Academy of Sciences (NAS). In addition, within the United States, content standards are specified most typically at the state and at the local district level. The resulting fragmentation and lack of coherence for the US system as a result of this configuration has been discussed elsewhere.

For the state of Minnesota at the time of the TIMSS testing no official state content standards existed. Neither was there a statewide assessment. This has currently changed as new educational policy is being implemented in the state.

The absence of such state content standards, however, had different implications for mathematics and science. In mathematics the void was filled by local content standards. In science course offerings were fairly consistent statewide especially in grades seven and eight. At seventh grade the content area studied is biology in almost all schools while at eighth grade the focus of instruction is on earth science. Teachers throughout the state cover these content areas and also use the same or very similar textbooks for their instruction.

Informal communications with leaders in the state of Minnesota suggest a presence of what we shall term *de facto* state standards at least in science for grades seven and eight. As stated above, there were at that time no official state standards but through strong leadership at the state level as well as general cooperation on the part of teachers across the state, in effect Minnesota had what would be very close to state standards.

These standards were further supported by teacher certification requirements, which were very specific to the sub areas of science, i.e., biology versus earth science. Individuals in order to teach at eighth grade had to be certified in earth science in the state of Minnesota.

Although there were no official state content standards in science at the time of the TIMSS testing, because of the presence of *de facto* standards, we asked certain state officials to respond to a process we used in the original TIMSS study to indicate what the official, or in this case unofficial, standards were for the state at each grade in science. Given that the same type of *de facto* state content standards did not exist in mathematics, we did this only for the area of science. Those results are now reported.

It is important to keep in mind that from Minnesota's point of view the *de facto* science content standards were not official standards but from a research point of view aimed toward understanding the Minnesota results they functioned in much the same way.

Number of Topics Intended for Focus

Exhibit 5 indicates the international distribution of the number of science topics intended to be taught at each of grades one through eight. Also included are points representing the US and a composite for the top achieving countries of TIMSS. What is remarkably and immediately clear is that Minnesota intends (as defined by the *de facto* standards) far fewer topics to be taught at each grade level than is true for the United States as a whole.

In fact, the pattern for Minnesota is similar to that of the top achieving countries in the first few grades but then implies even fewer topics to be taught, especially at grades six, seven, and eight. In other words, in contrast to what has been reported elsewhere as the "mile wide inch deep" curriculum for the United States as a whole, Minnesota seems to have a much more focused curriculum especially at the upper middle grades.

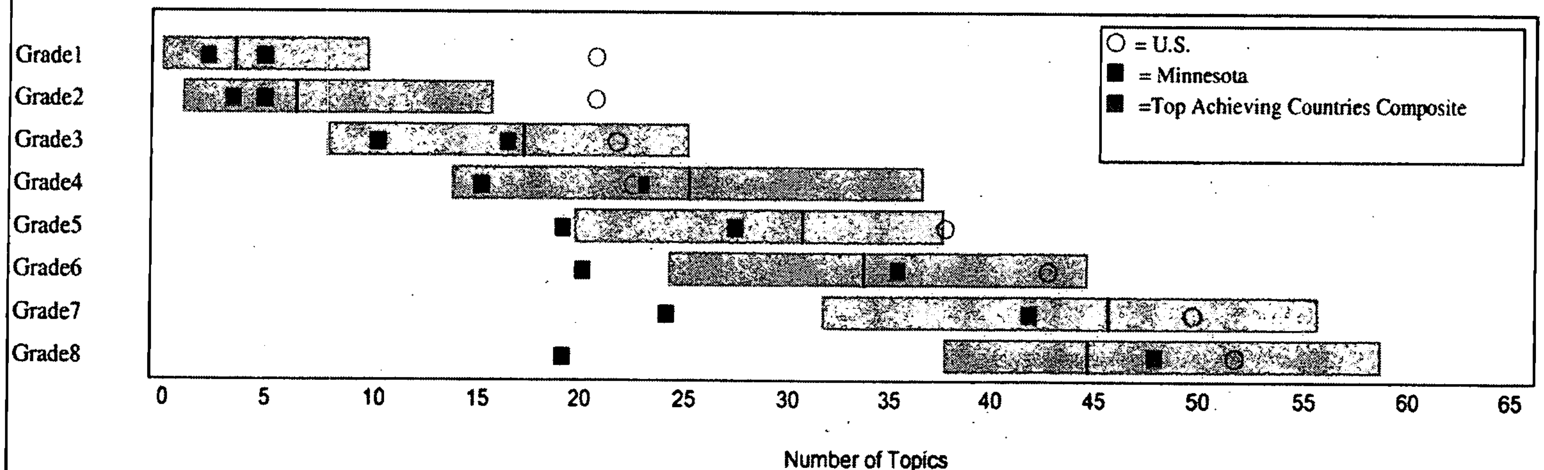
Exhibit 6 shows the same type of display but focusing on each of the top achieving countries individually instead of as a composite. In eighth grade science Minnesota intends only some 20 topics while Japan for example intends some 35+ topics. Minnesota seems to have a much more focused curriculum at this grade level than these other countries.

Exhibit 7 sheds further light on this focus in the Minnesota curriculum in science at grades seven and eight. In this exhibit, the average number of grades for which a typical topic remains in the curriculum when compared to the international average is displayed. Minnesota exhibits a pattern showing that topics are taught for a relatively shorter period of time and then removed from the curriculum.

Exhibit 8 indicates the science topics that are intended at each grade for the state of Minnesota, using as a template the topics that are primarily covered in the top achieving countries. What is immediately clear is that there are certain topics, which are intended to remain in the science curriculum across the first 8 years. Those topics include "physical cycles", "weather and climate", "life cycles", "animal types", and "plants and fungi."

Exhibit 5

Number of science topics intended. On average, the states indicated plans to cover so many topics that the U.S. composite shows more science topics generally covered than the median for other countries. The number of topics to be covered dropped significantly only in grades 10, 11, and 12 (below the 25th percentile in grades 11 and 12). We appear, in these later grades, to have abandoned more general sciences approaches for specific courses — chemistry, physics, etc. [The gray bars show how many mathematics topics we intended to cover at each grade in the TIMSS countries. The bars extend from the 25th percentile to the 75th percentile among countries. The black line indicates the median number of topics at each grade.]



59

60

Exhibit 6

Number of Science Topics Intended for Each Grade by Content Standards

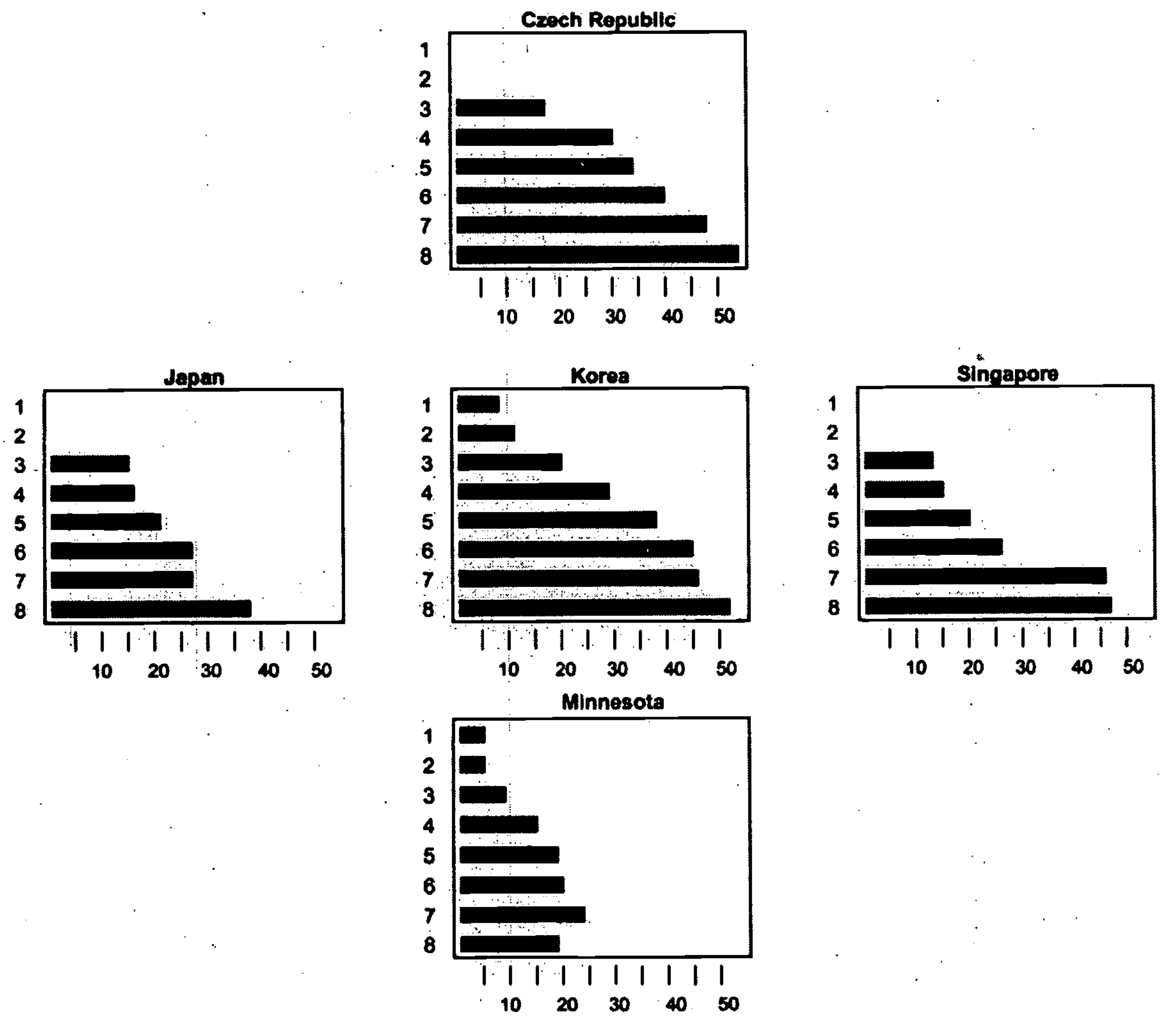
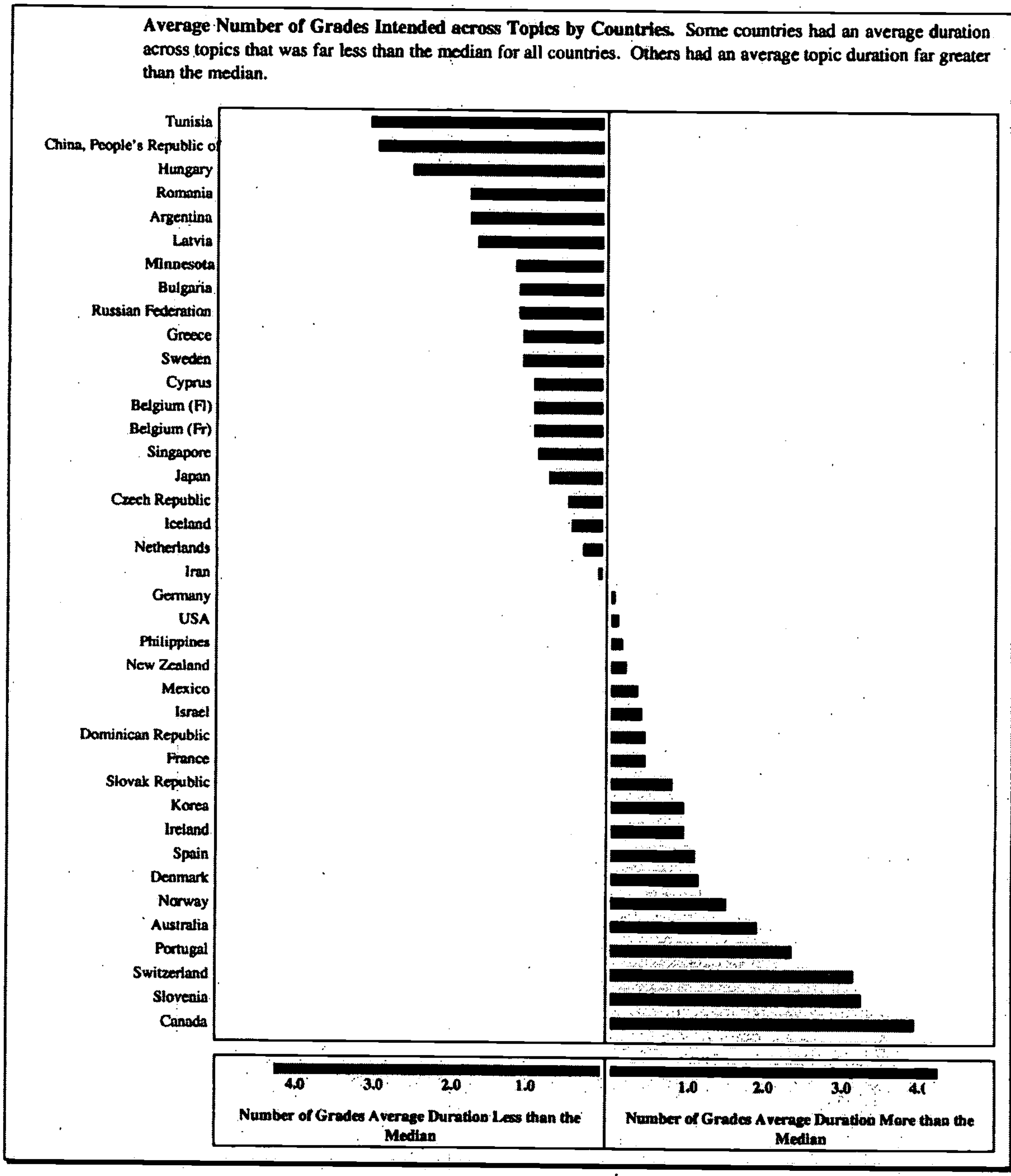


Exhibit 7



Average Number of Grades Intended across Topics by Countries. Some countries had an average duration across topics that was far less than the median for all countries. Others had an average topic duration far greater than the median.
Tunisia
China, People's Republic of
Hungary
Romania
Argentina
Latvia
Minnesota
Bulgaria
Russian Federation
Greece
Sweden
Cyprus
Belgium (Fl)
Belgium (Fr)
Singapore
Japan
Czech Republic
Iceland
Netherlands
Iran
Germany
USA
Philippines
New Zealand
Mexico
Israel
Dominican Republic
France
Slovak Republic
Korea
Ireland
Spain
Denmark
Norway
Australia
Portugal
Switzerland
Slovenia
Canada
4.0
3.0
2.0
1.0
Number of Grades Average Duration Less than the Median
1.0
2.0
3.0
4.(
Number of Grades Average Duration More than the Median

62

Exhibit 8

Science Topics Intended at Each Grade by Minnesota.

Topic	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6	Grade 7	Grade 8
Organs, tissues						●	●	●
Physical properties of matter								
Plants, fungi	●	●	●	●	●	●	●	●
Animal types	●	●	●	●	●	●	●	●
Classification of matter								
Rocks, soil								
Light								
Electricity						●	●	●
Life cycles	●	●	●	●	●	●	●	●
Physical changes of matter								
Heat & temperature								
Bodies of water								
Interdependence of life					●	●	●	●
Habitats & niches						●	●	●
Biomes & ecosystems							●	●
Reproduction								
Time, space, motion								
Types of forces						●	●	●
Weather & climate	●	●	●	●	●	●	●	●
Planets in the solar system								
Magnetism						●	●	●
Earth's Composition								
Organism energy handling								
Land, water, sea resource conservation							●	●
Earth in the solar system								
Atoms, ions, molecules								
Chemical properties of matter								
Chemical changes of matter								
Physical cycles	●	●	●	●	●	●	●	●
Land forms								
Material & energy resource conservation								●
Explanations of physical changes								
Pollution					●	●	●	●
Atmosphere								
Sound & vibration								
Cells								
Human nutrition								
Building & breaking						●	●	●
Energy types, sources, conversions					●		●	●
Dynamics of motion								
Organism sensing & responding								
Evolution, speciation, diversity								
Number of additional topics intended, on average, by FIW districts to complete their curriculum at each grade level.	7	5	9	12	10	13	16	23

Intended by *Minnesota* ●

The other thing that is noticeable is that the eighth grade intended curriculum seems to focus mostly on topics related to earth science, ecology and environmental science. Another very noticeable conclusion that can be drawn from Exhibit 8 is that many of the topics intended in the curriculum for the top achieving countries (base number of topics listed in the display) are not intended to be taught in the Minnesota curriculum. This might well explain the results noted in Exhibits 5 and 6.

Many of the topics that are not intended for coverage in the Minnesota curriculum at any of the grades but especially at grade eight pertain to physics and chemistry. If one were to add the 10-15 topics that define those areas in the top achieving countries to the Minnesota curriculum at eighth grade one would find that the results in Exhibit 5 would be more similar to that of Japan and Singapore for example.

What the results in Exhibit 8 further suggest is that the *de facto* standards call for the inclusion of biology in grade seven, earth and environmental science at grade eight, and the virtual exclusion of physics and chemistry from either. This pattern of unofficial intentions if implemented by teachers would be very consistent with the achievement status and gain patterns reported in the previous sections.

At eighth grade in science Minnesota did extremely well overall, being outperformed statistically by only one nation, Singapore — and on the sub-areas Minnesota was tied with Singapore for the highest score on the earth science subtest but also did extremely well on the life science subtest. The areas of poorer performance for Minnesota were in chemistry and physics. In the area of environmental science Minnesota scored second only to Singapore.

These results, together with those discussed in the previous sections are totally consistent with the intentions as reflected in the previous Exhibits 5-8. One finds a focus present in the Minnesota science curriculum that is not present in its mathematics curriculum nor one that is present in either the mathematics or science curriculum of the United States as a whole.

Three of the characteristics discussed elsewhere as lacking in the US curriculum as a whole — focus, coherence, and international rigor — seemed much more to be present for Minnesota science at seventh and eighth grades. Not only is focus present but there is a coherence about the science curriculum concentrating on a small number of topics all within a given area that cohered together within the broader sense of the discipline.

The resulting achievement patterns for Minnesota seem very consistent with these curricular intentions. The down side to the Minnesota achievement results is also consistent with its curricular intentions. Minnesota does not intend much instruction in chemistry and physics probably outside of the chemistry that is needed to support earth science. The achievement patterns reported earlier showing Minnesota's poorest overall achievement status in those areas, as well as gains that place them near the bottom of the international distribution, would be consistent with such an intention if it were implemented.

In summary, Minnesota's performance on the TIMSS achievement test seems totally consistent with the pattern of science intentions as reflected in the unofficial specification of intentions for the state. It is important to again remind the readers that these intentions were not official state content standards at that time but merely reflected the *de facto* standards that were arrived at by consensus through strong leadership at the state level.

Both the pattern of achievement and the pattern of intentions for Minnesota at grade eight are much more consistent with the patterns that one finds in the top achieving countries. The point here is not whether a focus on earth science at eighth grade and a focus on biology at seventh grade to the exclusion of any focus on physics and chemistry is appropriate or not. The point is that this focus resulted in a coherence across the state. With supporting teacher certification, these seem to be an important correlates of Minnesota's strong performance in earth and environmental sciences at eighth grade and a continuing strong performance in biology. Although the gain patterns from Minnesota in biology at eighth grade imply, as one might expect, that most of what was learned in biology was learned in the previous grades — mostly likely seventh grade. The caution to be raised here with respect to Minnesota's curriculum is the absence of content standards for physics and chemistry, which are the more rigorous and fundamental topics demanded in the curriculum of the top achieving countries.

What Minnesota teachers actually teach

So far we have examined Minnesota's science content standards as they were reflected in the semi-official intentions that were present in 1995. We can also examine what Minnesota teachers actually taught in mathematics and science according to the TIMSS questionnaire data. This is in contrast to the previous section where we only discussed the unofficial intentions in science. This portrait provides a different picture of the curriculum in mathematics and science — curricula as they are enacted by teachers in their classroom activities.

How much do Minnesota teachers teach?

Exhibits 9, 10, 10B, 11, 11B, 12 and 12B help once again to restate the point, rather dramatically, that US teachers as a whole typically taught more topics than teachers in other countries. The exhibit has two panels, one for the number of mathematics topics taught by fourth grade teachers and another for the number of science topics taught by those teachers (since most often teachers taught both at this grade level). Within a panel, each row represents the topics covered by one teacher as was reported on the TIMSS questionnaire. Each column represents one of the topics about which the teachers were surveyed. The panel for science has more columns than does that for mathematics as the teachers were asked about more science topics.

The columns are arranged so that the most commonly taught topics are towards the left of each panel. The rows are arranged so that the teachers who covered the most topics are towards the top of each panel (the row of corresponding rank does not necessarily represent the same teacher in both panels). The line drawn within each panel connects the points of each row representing the total number of topics taught by that rows teacher

Exhibit 9

Number of topics covered by sampled fourth grade students' mathematics and science teachers for a selected set of countries.

Number of topics covered by sampled fourth grade students' mathematics and science teachers for a selected set of countries.

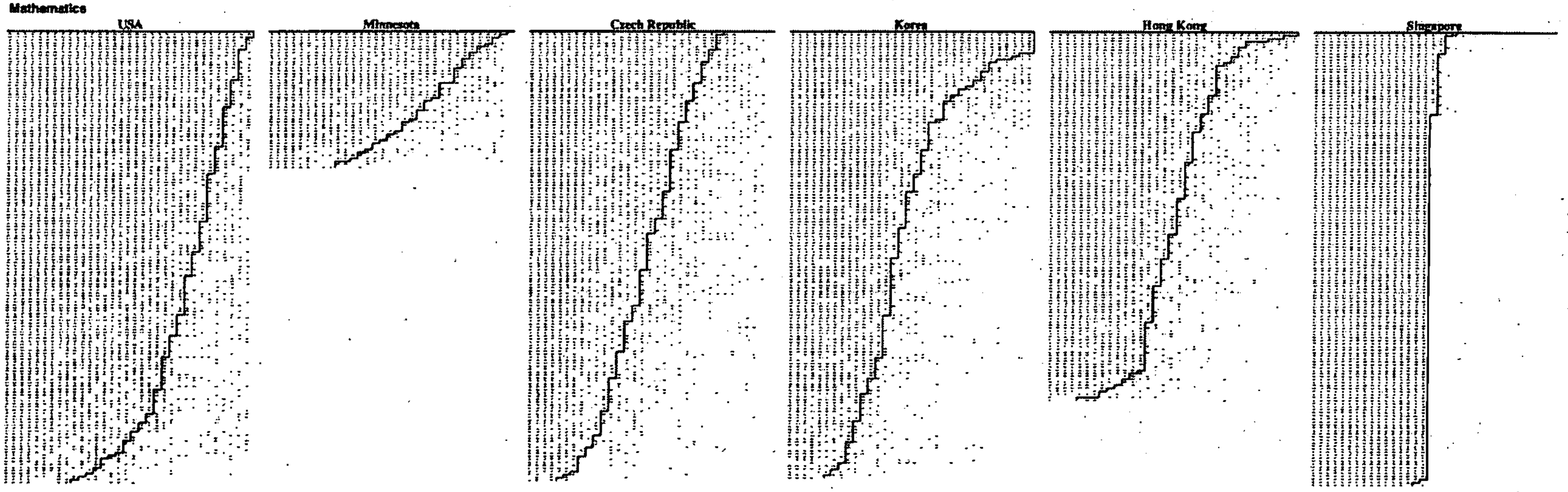


Exhibit 10

Number of topics covered by sampled fourth grade students' mathematics and science teachers for a selected set of countries. (page 1)

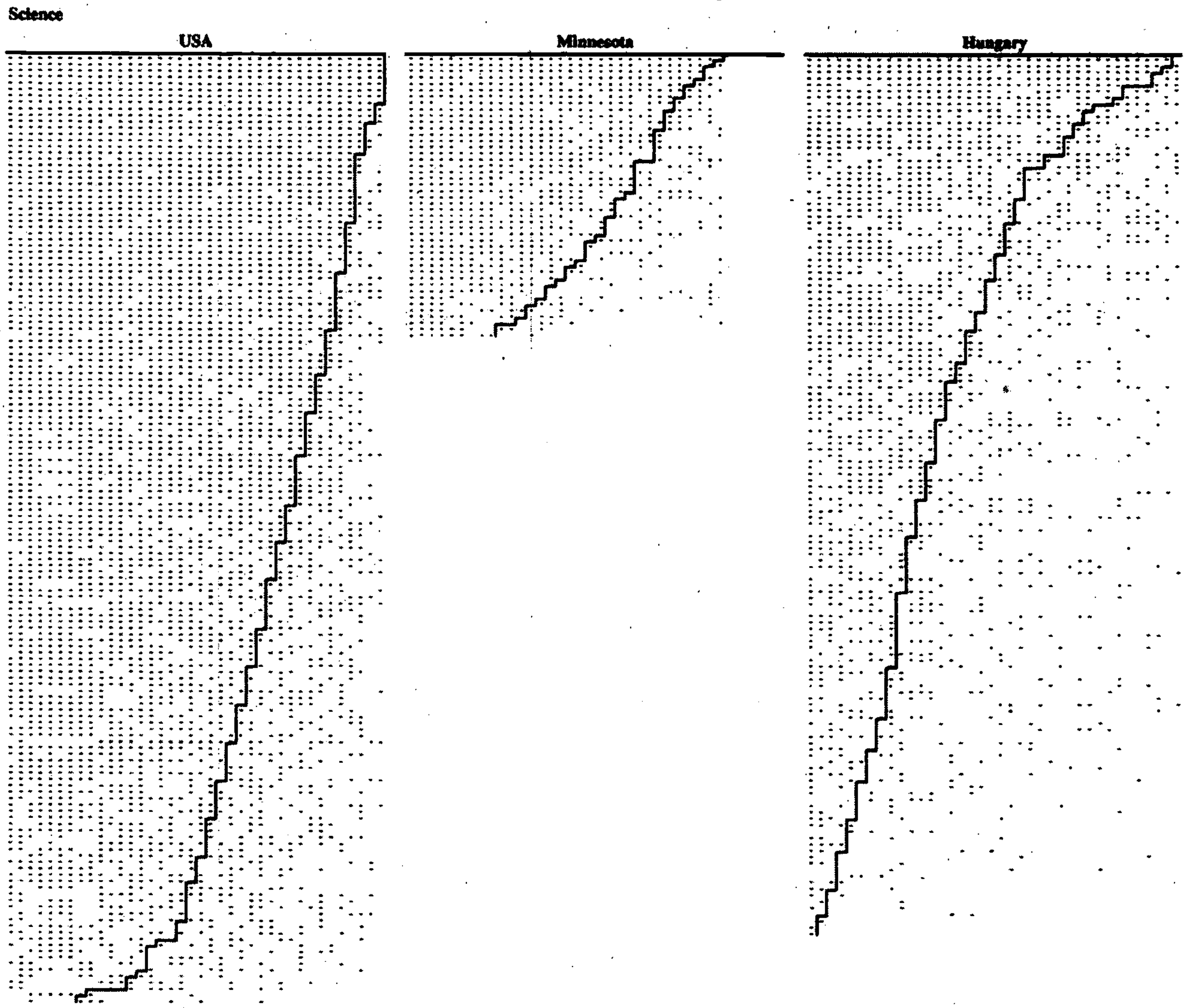


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Exhibit10B

Number of topics covered by sampled fourth grade students' mathematics and science teachers for a selected set of countries.

Science

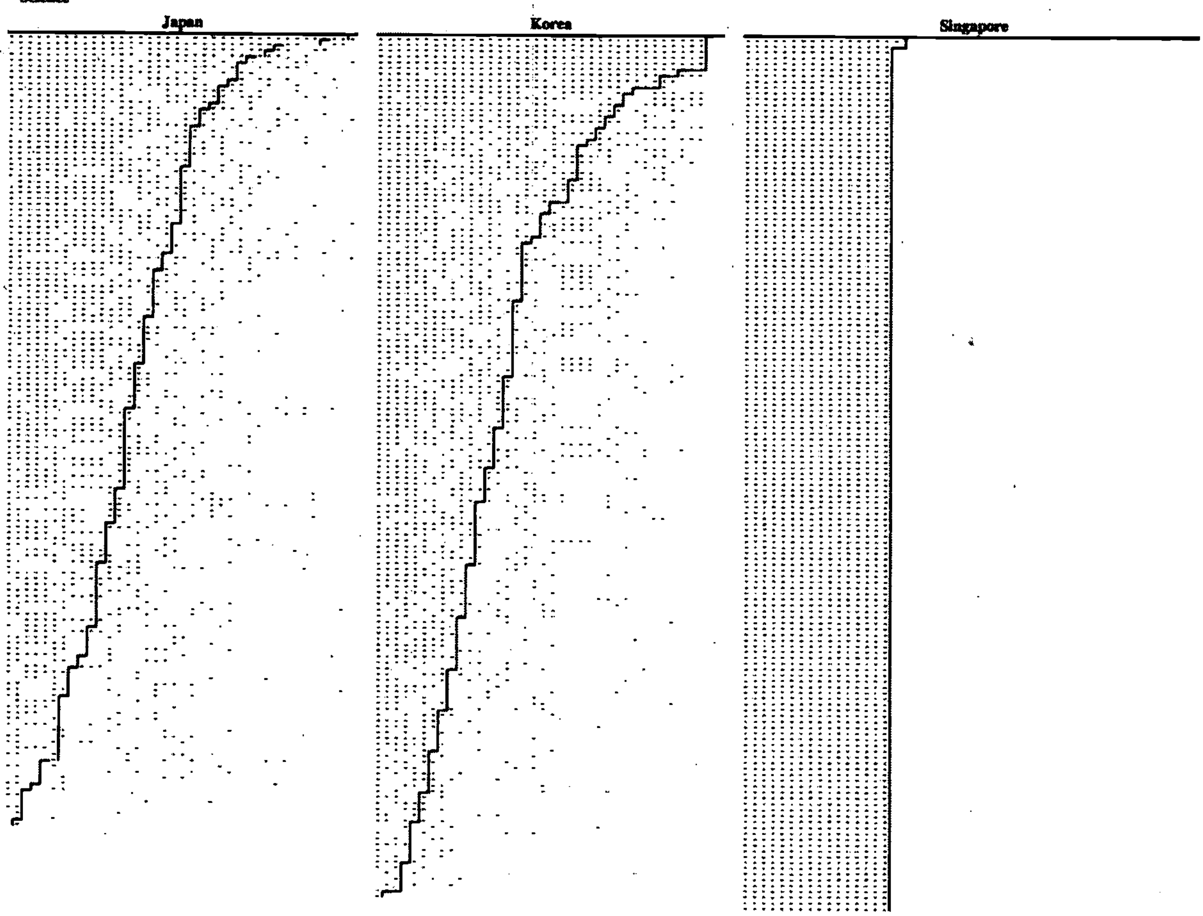

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Exhibit 11

Number of topics covered by sampled eighth grade math teachers in selected countries.

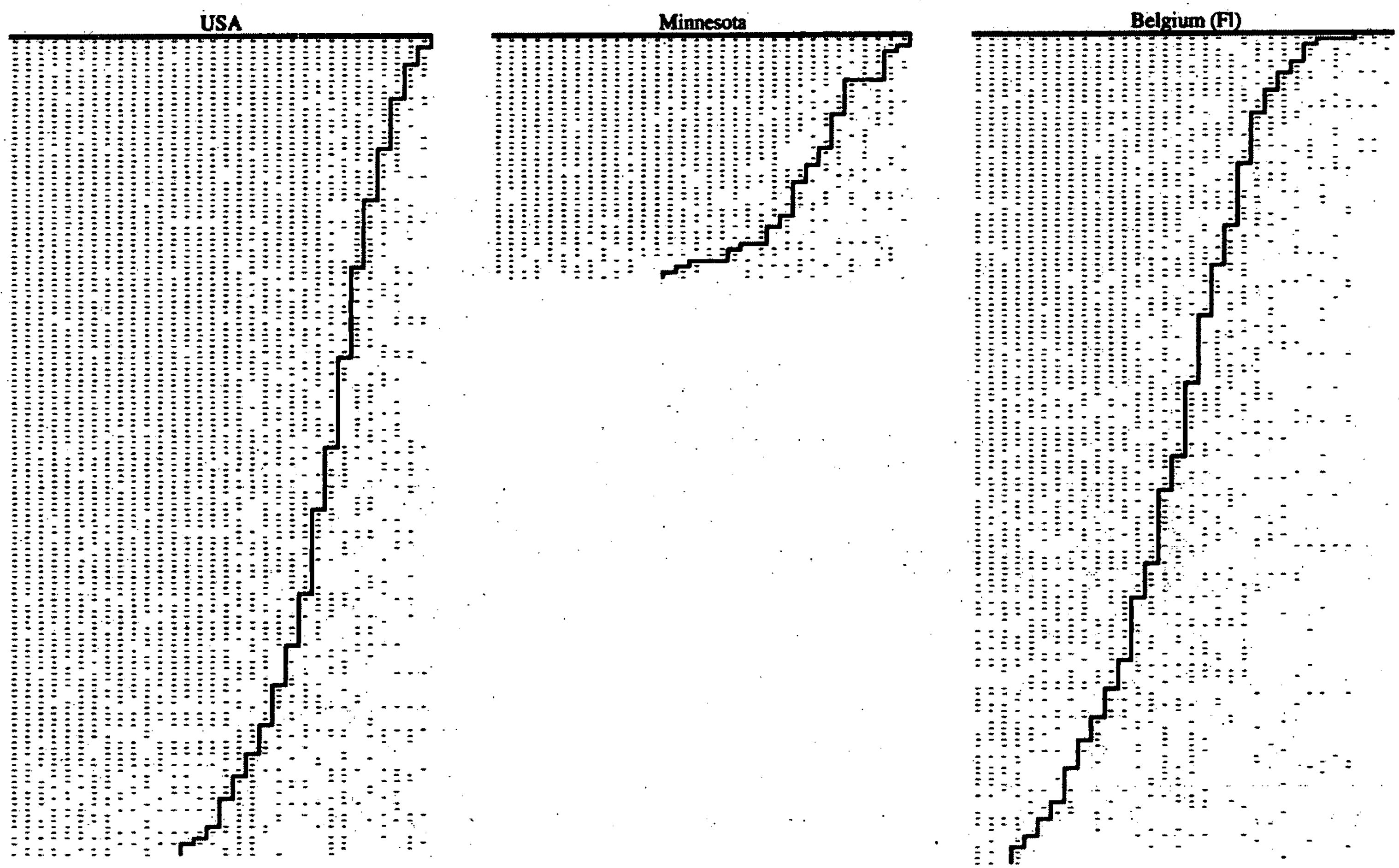

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Exhibit 12

Number of topics covered by sampled eighth grade science teachers in selected countries.

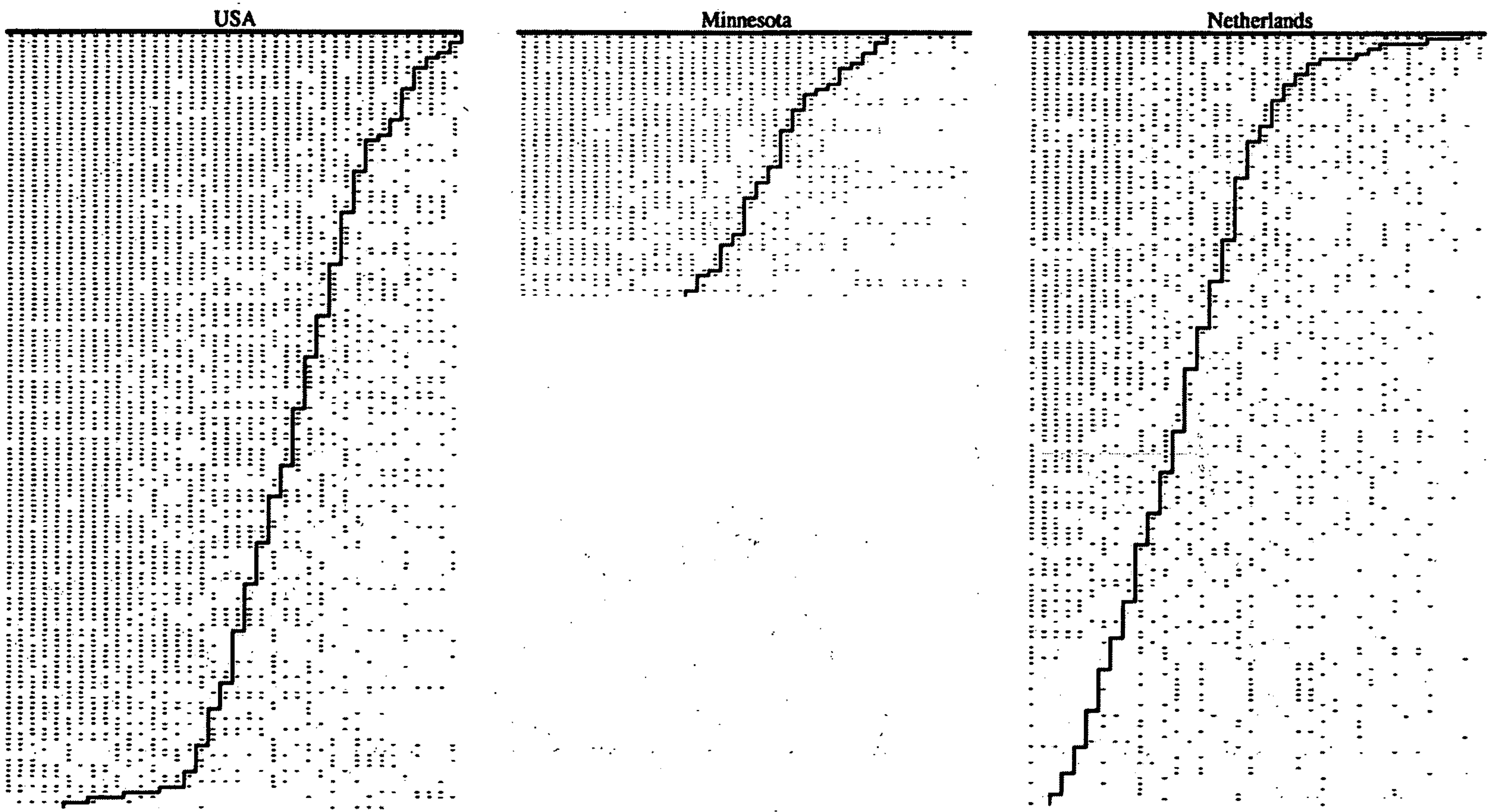
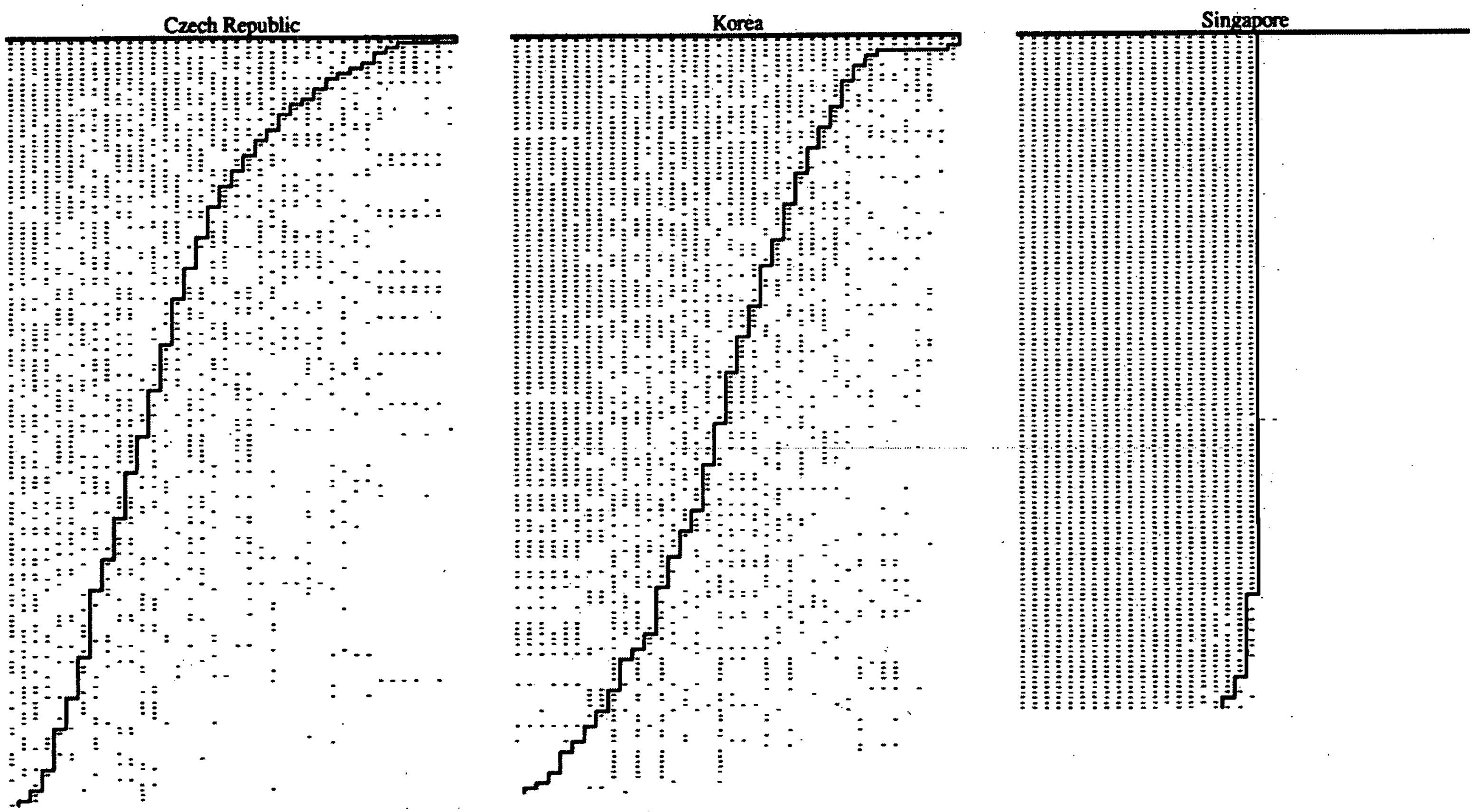


Exhibit 12B

Number of topics covered by sampled eighth grade science teachers in selected countries. (continued)



75 76

with similar points for other rows (other teachers).

The result is a visual display on how many topics were taught by a representative sample of the fourth and eighth grade teachers in mathematics and science.

For Minnesota the results suggest a similar pattern to that of the US as a whole in mathematics and in science at fourth grade. In all three of these cases, the numbers of topics taught by the Minnesota teachers is very similar to that of the US as a whole. This suggests that in mathematics the "mile wide inch deep" curriculum characteristic of the US as a whole is also characteristic of Minnesota instruction.

The results for science at eighth grade do seem to be different. Here the curve, as well as the display, seem to reflect that science teachers teach fewer topics than is characteristic of the US as a whole. This reflects patterns much more consistent with those of other countries. These results, together with those presented in the previous section representing the *de facto* standards, coincide to make the point that Minnesota instruction at eighth grade in science seems more focused, representing a fewer number of topics being actually taught in the classroom.

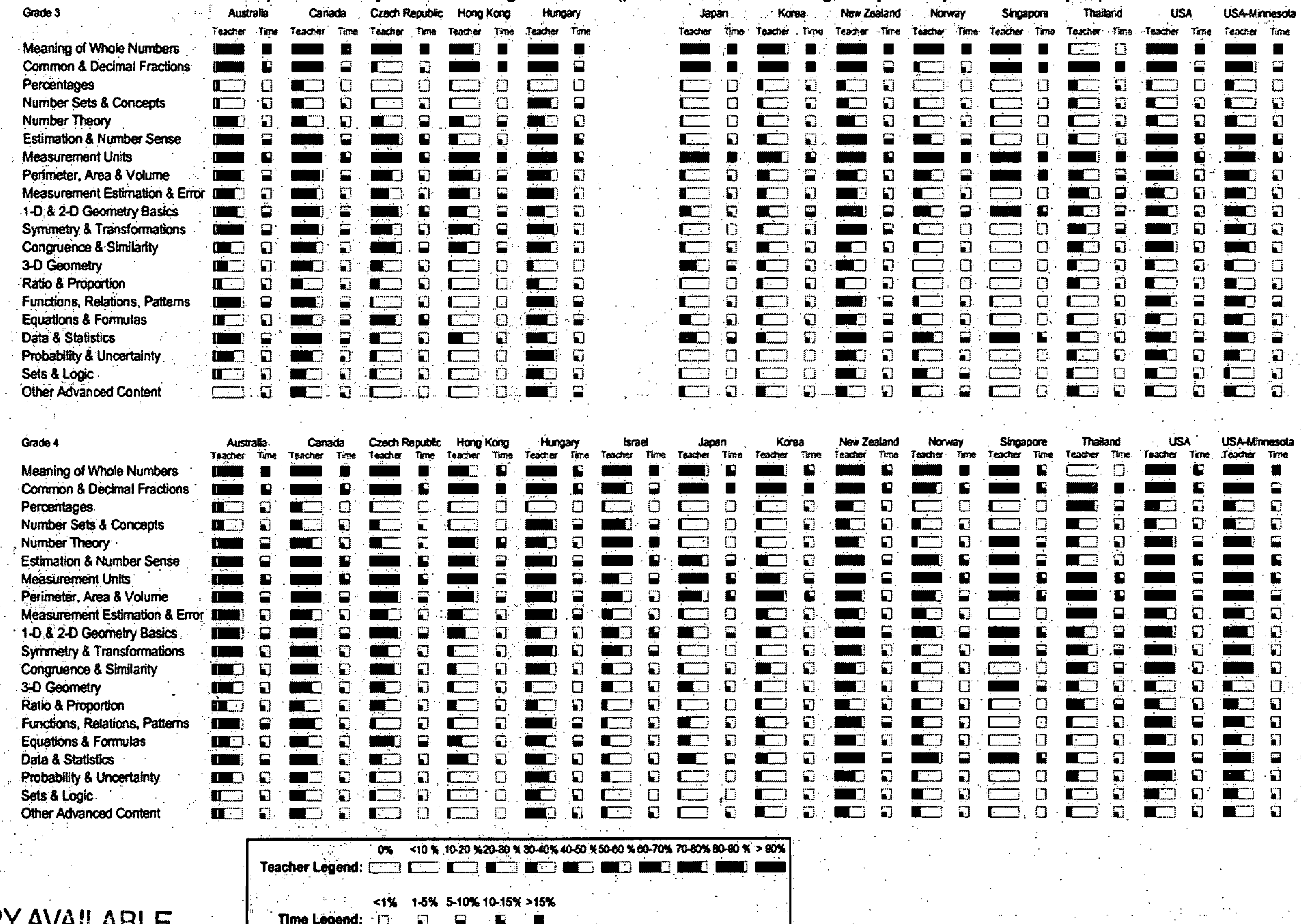
What they teach?

Which topics do Minnesota teachers most commonly cover? Exhibit 13 examines the specific topics covered by US third and fourth grade mathematics teachers. This exhibit displays the percentage of US, Minnesota and other countries' third and fourth grade teachers teaching the various mathematics topics as reported on the TIMSS questionnaires. Along with this display of the percentage of teachers covering the various topics, the exhibit also displays the average percentage of time reported as spent on each topic.

The focus of the discussion that follows concerns what Minnesota teachers taught, although the exhibits also display the same information for teachers in the US as a whole, as well as in other TIMSS countries. This provides an international comparison for what Minnesota teachers taught. The general conclusion from Exhibit 17 from a cross-country

Exhibit 13

Mathematics topics covered by third and fourth grade teachers (percent of teachers covering the topics and percent of time spent)



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perspective is that there is great variability in what teachers taught.

In Mathematics

Exhibits 13 and 14 display the results described in the preceding paragraphs for mathematics for third, fourth, seventh and eighth grade teachers. For seventh and eighth grade, Minnesota teachers appeared to be identical in their content coverage and time allocations to that of US teachers as a whole. They cover many topics and with little focus on any one topic. The only topic at both seventh and eighth grades to receive any major type of focus is common and decimal fractions.

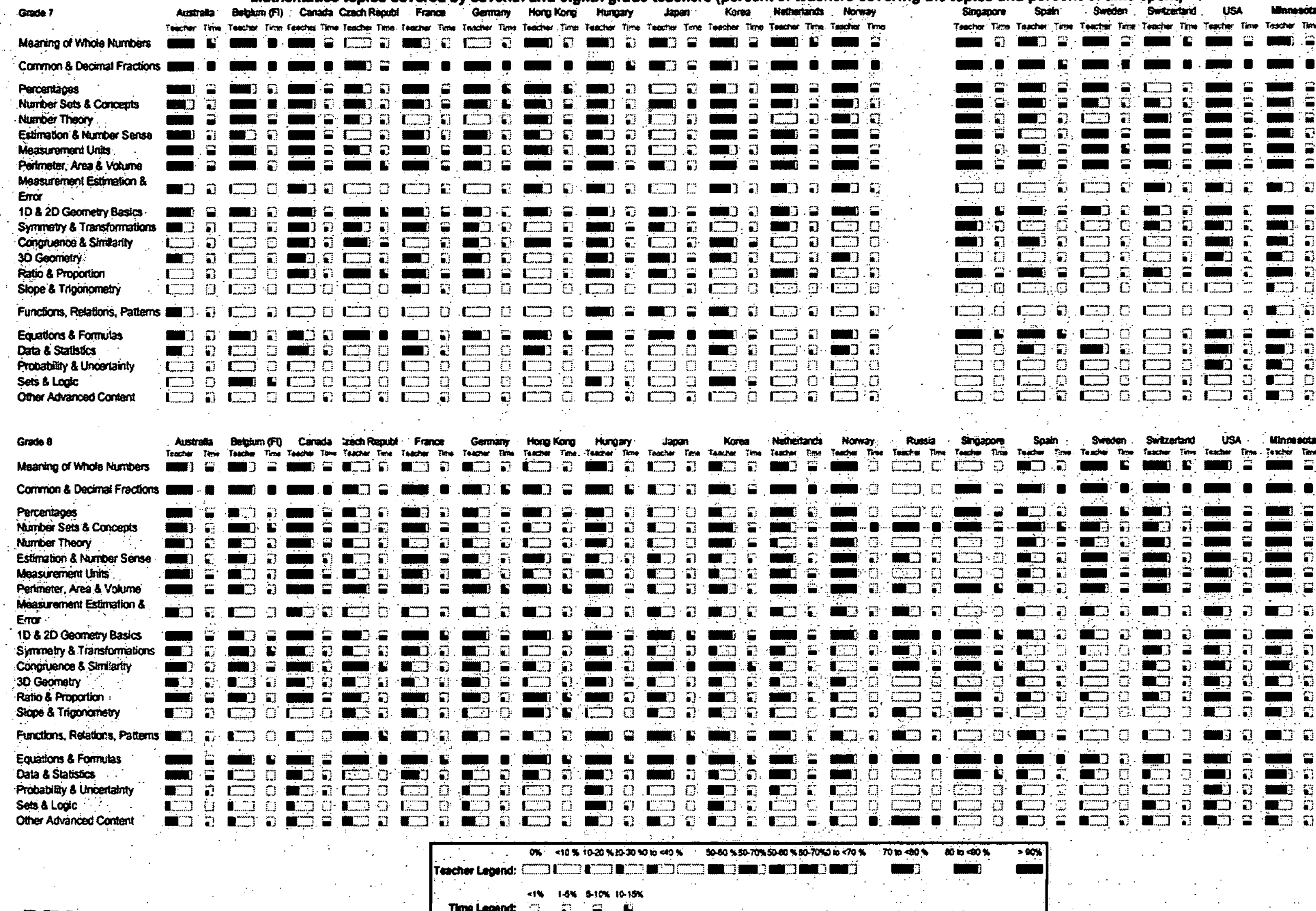
As a result of being like the US as a whole, Minnesota teachers in mathematics at seventh and eighth grade are very different from teachers in many of the other countries where one sees much more of a curricular focus and emphasis on a limited number of topics to the virtual exclusion of other topics from the implemented curriculum. This pattern of instruction, characterized as "mile wide inch deep," would likely result in the gain patterns discussed in the previous sections. Minnesota students gained very little in all the areas, placing them very low in the international rankings in terms of gains.

At eighth grade, one of the few areas in which Minnesota students' gain was large was "measurement units." When contrasting the percentage of time allocated to "measurement units" by Minnesota teachers compared to the US as a whole, one finds almost twice as much time being allocated to the study of that topic compared to the US as a whole.

The results for grades three and four mathematics present a picture of Minnesota teachers that is diverges from the US as a whole. Both third grade and fourth grade Minnesota teachers are somewhat more focused although not nearly as focused as teachers in some of the other nations. Several topics covered by third grade teachers in the US as a whole were not taught by any Minnesota teachers. These topics include "percentages", "number concepts", "number theories", "3-D geometry", "ratio and proportion", "probability", and "other advanced" content. Some of those very same topics were also not taught by any

Exhibit 14

Mathematics topics covered by seventh and eighth grade teachers (percent of teachers covering the topics and percent of time spent)



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Minnesota fourth grade teachers compared to US teachers as a whole.

Other than these differences, Minnesota teachers looked very similar in their profile of coverage and in their emphasis at both the third and the fourth grade. Here again, one would conclude in general that Minnesota teachers reflect the "mile wide inch deep" curriculum, teaching many different topics with little focus in terms of time on any one of those topics.

Only a curriculum that was composed largely without any focused attention would consistently produce at best modest gains across the content areas. However, this is exactly the pattern of the US in mathematics at both fourth and eighth grades. The data from the previous sections reflecting the small gains in all areas, with few exceptions, from mathematics in Minnesota are consistent with a curriculum that is "a mile wide and an inch deep". The Minnesota curriculum appears to be like the US in that it rarely allocates focussed attention to specific topics.

Minnesota, as the US, has adopted a unique curricular strategy — or perhaps strategies since the means of being "a mile wide and an inch deep" differ. Given the concomitant achievement gains linked with that curricular strategy at fourth and eighth grade in mathematics, we can only consider that approach risky and unproductive since it was associated with only modest gains and average cumulative achievements in most content areas and in situations where curricula differences were the only likely explanation for achievement differences.

While cause and effect can not be unambiguously assigned to this kind of study, the Minnesota achievement data in mathematics and the curriculum data are at least consistent with this possibility.

One of the difficulties in making such comparisons for seventh and eighth grade in mathematics has to do with the practice of tracking in the United States. Minnesota also tracks in a similar fashion to what is done more generally in the United States. The question that this brings up is, are the patterns of similarities noted in the above exhibits similar or different across the different tracks.

Exhibit 15 shows these results for the algebra and other tracks in Minnesota as compared to the US. The patterns are totally consistent across the different types of tracks thus suggesting that the differences and the noted similarities of Minnesota teachers and US teachers as a whole are the same no matter to which track one is speaking.

Science

Exhibits 16 and 17 show similar results for science for third and fourth grade teachers. The data show third and fourth grade teachers in Minnesota to be very similar in their instructional emphasis to the rest of the United States teachers. The story, however, changes at the seventh and eighth grades as reflected in Exhibit 18.

Exhibit 18, which presents the data for the seventh grade teachers, indicates a clear pattern of focus on the part of the teachers on biology with some coverage of science and technology, history, and environmental science. Actually, all teachers teach the major biology topics during the seventh grade, and the two topics that receive the most focus in terms of percentage of instructional time are "diversity and structure of living things" and "human biology."

A majority of the teachers also covered two physics topics, "types and properties of matter" and the "structure of matter," but this instruction is probably related to those parts of physics necessary to cover biology at the cellular level. The data also make it clear that virtually no teachers teach earth science or the heart and core of physics and chemistry at seventh grade in the state of Minnesota.

The eighth grade results as presented in Exhibit 17 also paint a very different picture for instruction in Minnesota from that of the US as a whole. The pattern at eighth grade is not as clear as was the case at seventh grade with respect to how focused the instruction actually was. It is clear from Exhibit 17 that virtually all Minnesota teachers teach "earth

Exhibit 15

US eighth grade mathematics teacher coverage of 21 topics in algebra and non-algebra courses.

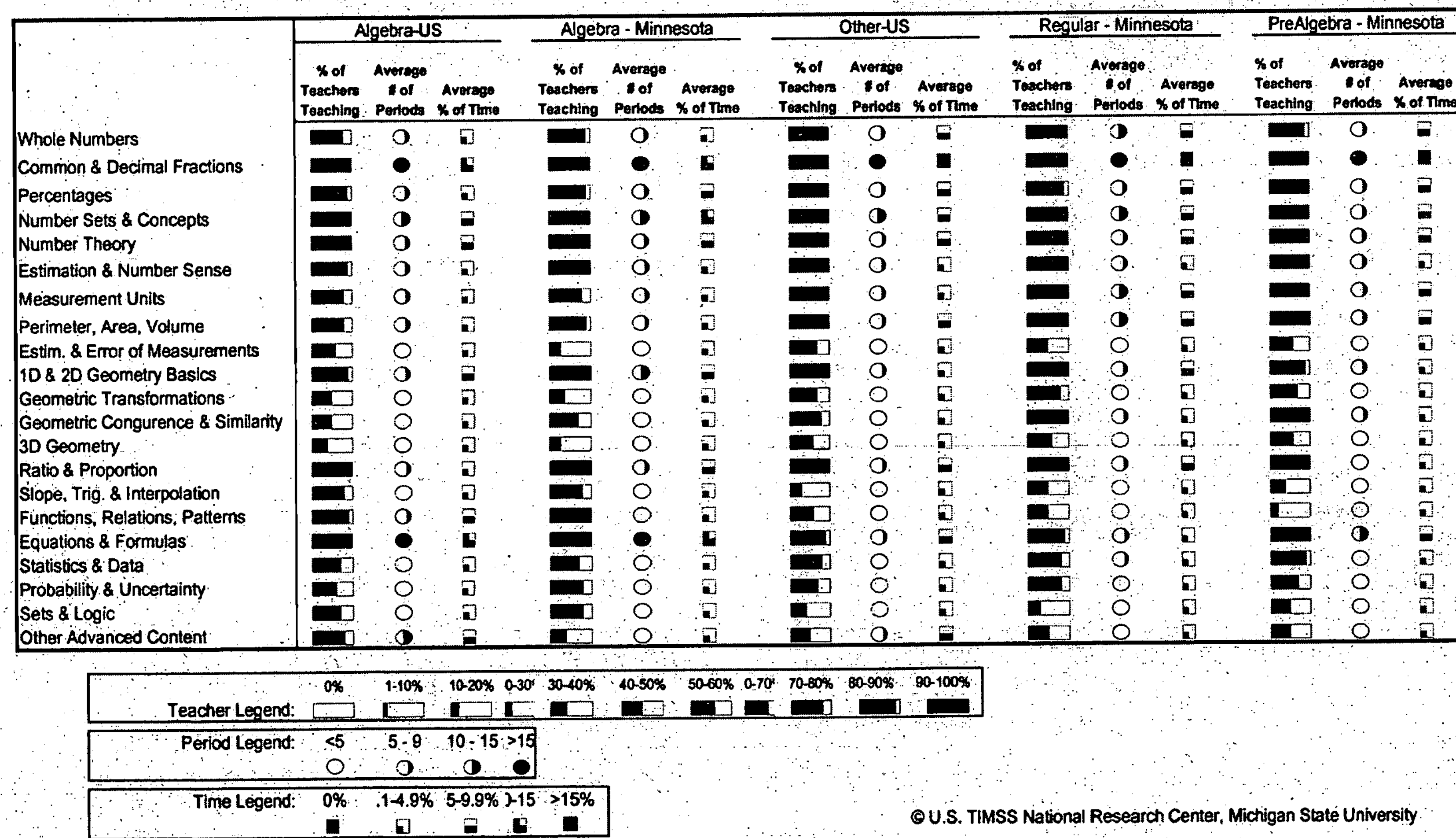

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Exhibit 16

Science Topics Covered By Third Grade Teachers (Percent of Teachers Covering the Topics and Percent of Time Spent)

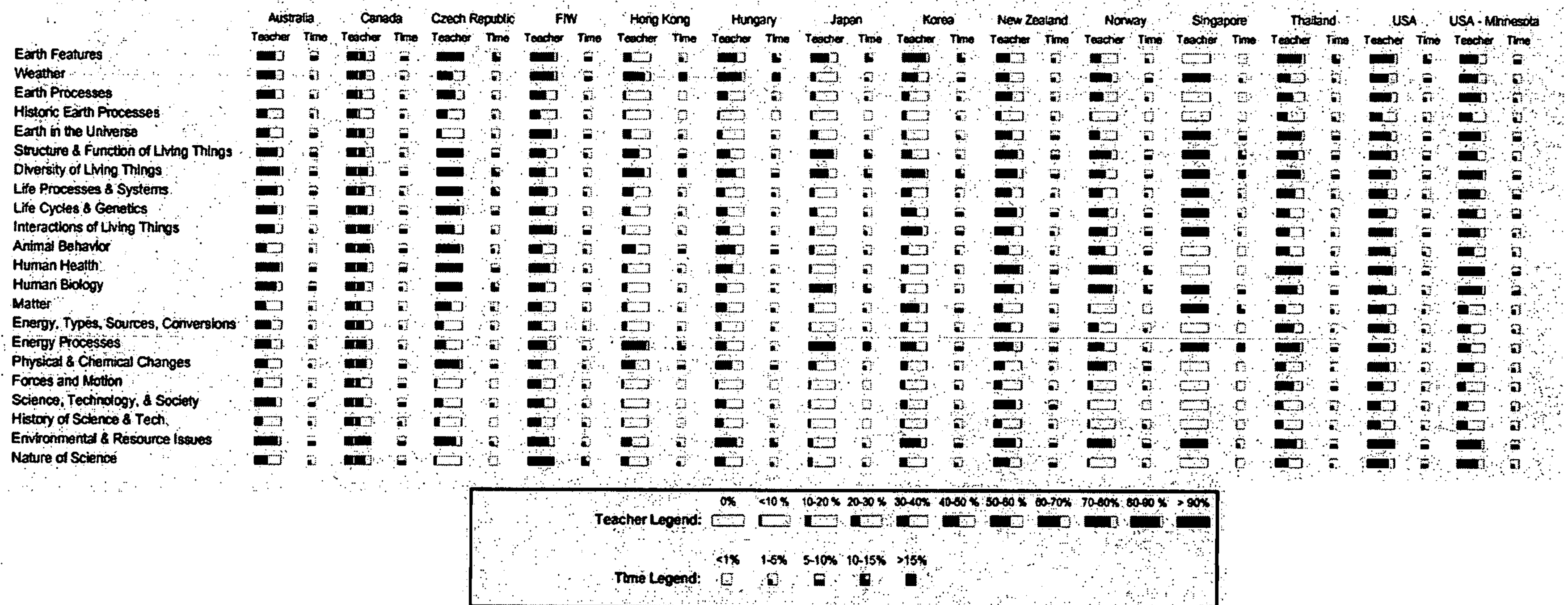

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Exhibit 17

Science topics covered by fourth grade teachers % of teachers covering topics and % of time spent)

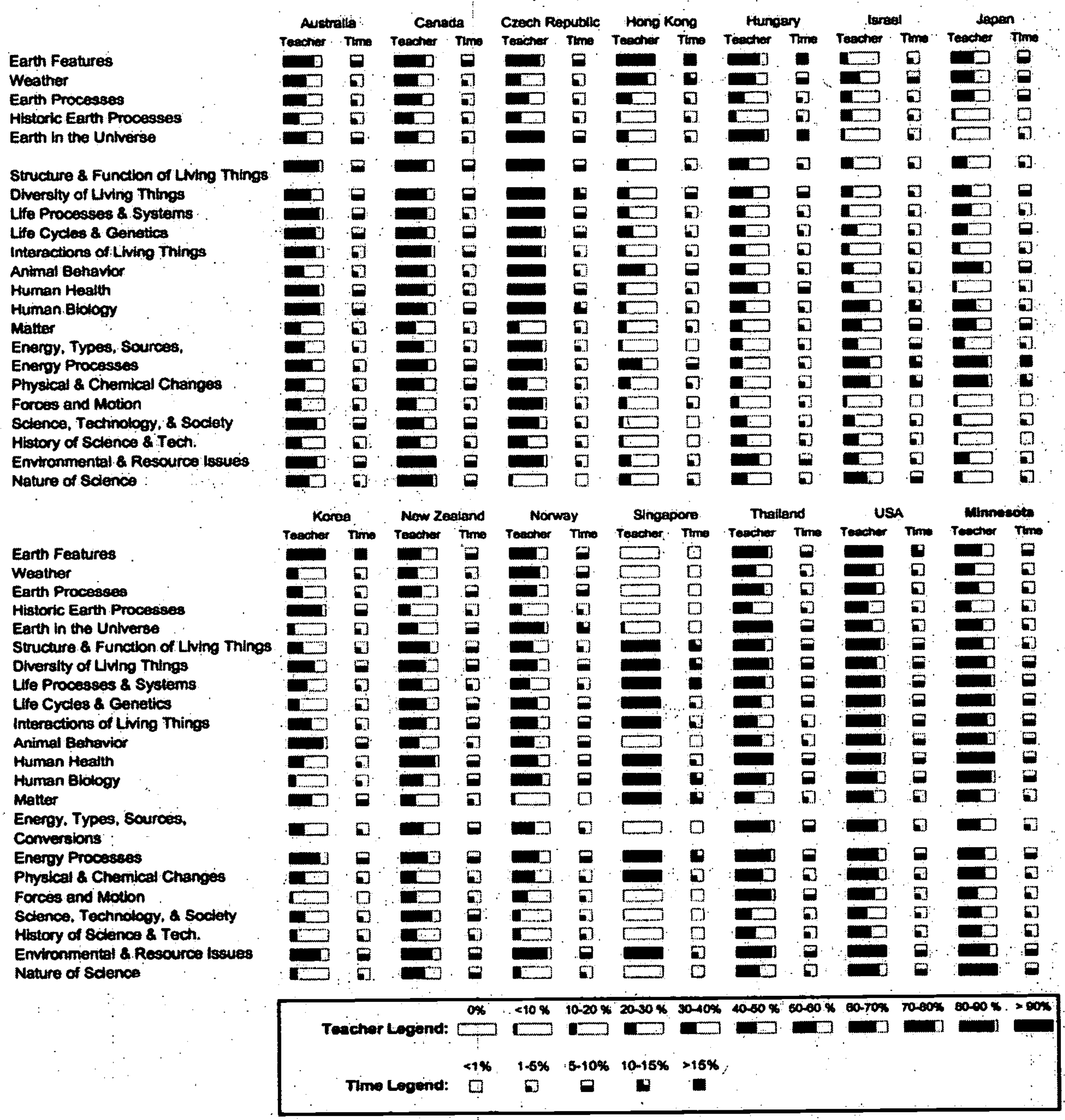
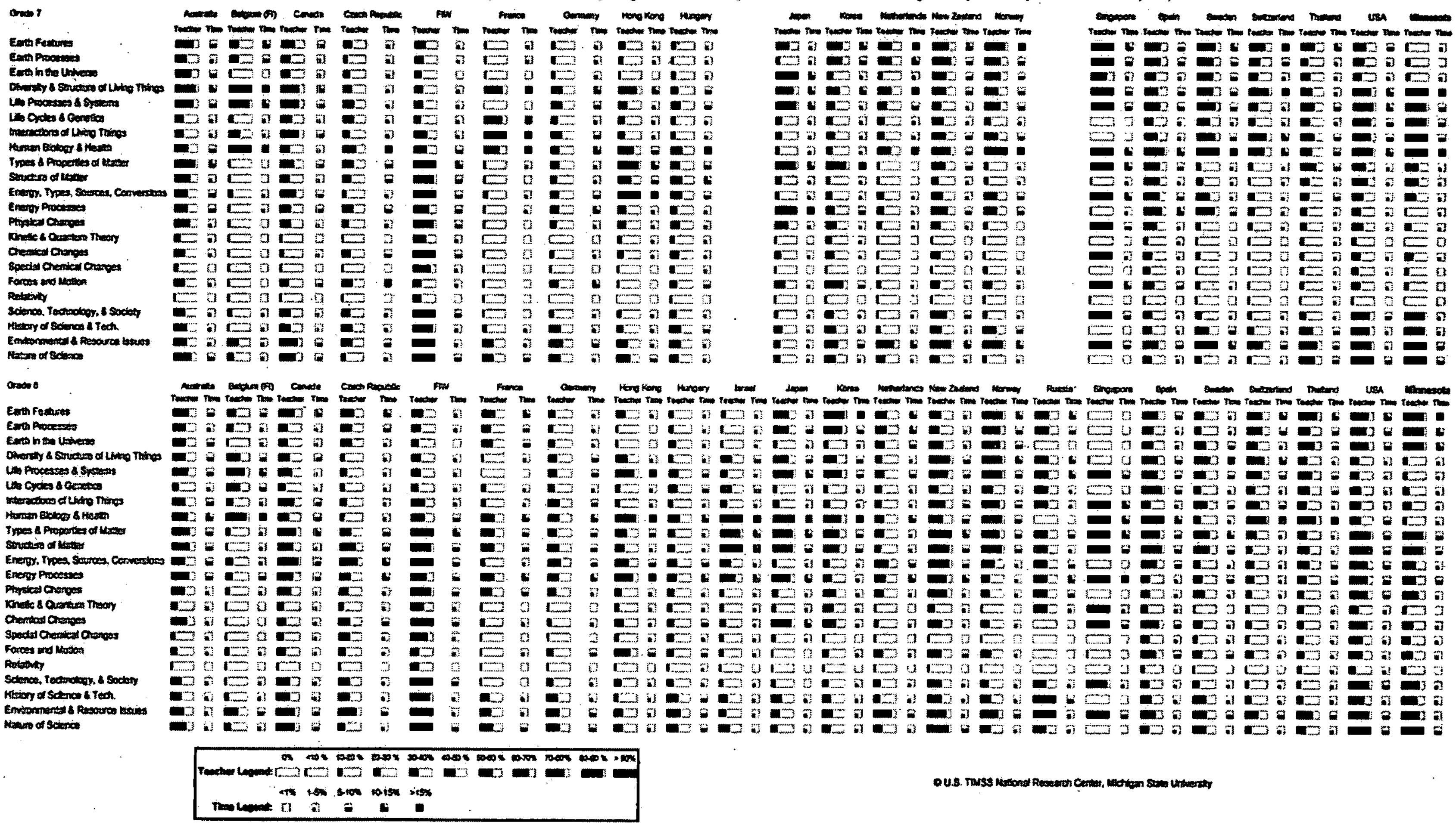


Exhibit 18

Science topics covered by seventh and eighth grade teachers (percent of teachers covering the topics and percent of time spent)



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features", "earth processes", and "earth in the universe" at eighth grade. These are the topics also that receive the major percentage of instructional time and represent the clear focus of instruction.

However, in contrast to the seventh grade where virtually no topics other than biology were being covered, many eighth grade teachers in Minnesota are also covering some physics topics, although they are not receiving as much instructional time as the earth science topics. Perhaps this reflects the fact that teaching earth processes such as plate tectonics and the water cycle requires a fairly sophisticated knowledge of physical forces and of the elements. Hence, the instruction really is much more related to earth science than it is to general physics.

The data also suggest that a few teachers in Minnesota allocate some small amounts of time for some of the biology topics. It is also clear from Exhibit 17 that the eighth grade Minnesota teachers do not teach chemistry other than the ways in which it might be related to earth science.

The Minnesota curriculum: a summary

The Minnesota curriculum in mathematics appears to be very similar to that of the United States as a whole. No *de facto* state standards existed in Minnesota at the time of the TIMSS test, and the teacher data reflect an approach to mathematics instruction that is very consistent with that of the US as a whole. The textbooks used by Minnesota teachers are very much the same textbooks used by teachers in the rest of the United States. There is a tendency on the part of Minnesota teachers to try to teach many topics at each grade. There is little resulting focus and the characterization of the US curriculum as a whole as "a mile wide and an inch deep" in mathematics seems to hold remarkably well for Minnesota.

The story in science is quite different. In grades three and four, the profile of what Minnesota teachers teach in science is very similar to that of US teachers as a whole. There is not much focus in their instruction as many topics are covered, and the nature of the topics taught seems very much the same.

At grades seven and eight, however, this pattern changes for Minnesota as compared to the US. The results of the analysis of the *de facto* intended curriculum for Minnesota combined with the data from the teachers themselves suggest a coherence that permeates Minnesota instruction at the seventh and eighth grades.

Seventh grade is devoted to instruction in biology. Almost every teacher in the state of Minnesota at this grade focuses primarily on human biology. This focus is done to the exclusion of virtually all other topics. The fact that Minnesota did very well at the eighth grade on the TIMSS achievement test in biology probably reflects that instructional focus.

It is interesting to note that the strong performance in biology is one year after the instruction, suggesting that focused and coherent instruction may well lead to better retention. Minnesota makes little or no gain in biology during the eighth grade. This would be consistent with the Minnesota curriculum since biology instruction at eighth grade does not exist to any widespread extent.

Eighth grade instruction in Minnesota focuses on earth science but also does include some physics topics. Teachers' reported data on the actual implemented curriculum is consistent with this general thrust. Earth science topics are taught by virtually all teachers in the state and those are the topics that receive the most instructional emphasis in terms of the percentage of instructional time allocated to those topics. Most of the biology and physics topics have less than 20 percent of the teachers teaching them and several topics have absolutely no Minnesota teachers teaching them.

In summary, the science instruction at the eighth grade in Minnesota seems to be focused, coherent and non-repetitive but does not seem to cover the chemistry and advanced physics topics covered in the most of the top achieving countries in either seventh or eighth grade. This, as suggested earlier is very consistent with the pattern of achievement for Minnesota. The policy question is when will the physics and chemistry be taught for all students.

Summary

At the outset of this paper we indicated that its purpose was not only to analyze Minnesota's performance from a policy perspective but also to examine the feasibility of using data collected in a large scale international study such as TIMSS to formulate state policy. The results presented in the previous sections suggest a pattern similar to the United States in certain ways but also quite different. The policy implications for Minnesota seem strong and powerful.

The general point emanating from many of the TIMSS publications is that not only does instruction in the sense of pedagogy matter, but curriculum also matters. What it is that we expect children to learn in each of the grades and how much focus coherence and repetitiveness are associated with those topics might be very important. Other reports show that the percentage of time allocated by teachers, books and instructional content standards do have an impact on the achievement patterns across countries.

Minnesota compared extremely well internationally in science at both fourth and eighth grade and not nearly as well in mathematics. We believe that the policy implication that curriculum is important is also true in Minnesota. In fact, Minnesota serves for the nation as a whole as an important proof of what works.

Americans like to be shown that something is possible. The Minnesota results show that a curriculum focused around a smaller number of topics can result in achievement that is more consistent with the top achieving countries. This was the case in Minnesota for science at eighth grade. A closer examination of the teacher data reflects instructional patterns consistent with what one might expect in a high achieving country.

The fact that Minnesota did well in earth science at eighth grade given their instructional focus in this area is not the point. This is not an advocacy for earth science being isolated into a separate instructional year and in particular being presented at eighth grade. These are policies that the state has to address itself. What is important is that a coherent focus on non-repetitive curriculum taught by teachers with a strong discipline background may well have a powerful impact on what is learned by those students in those grades. The fact that mathematics in Minnesota did not have similar successes even though it is basically the same children suggests, even more strongly than we were able to make a case for the US as a whole, that curriculum does matter.

For the state of Minnesota the particular implications seem strong — one might call into question the poor performance on the part of fourth graders in decimals. Even though they do very well in other areas, what does this imply? What implications might be relevant for the reform of the state standards in this area? The poor performance in mathematics in general but especially in eighth grade is worthy of further consideration. Might not the lessons from the science side be generalizable to mathematics as well?

Not addressed in this paper but clearly made evident is the decline in science performance by the end of secondary school. One must ask at the state level why students performing so strongly at the eighth grade should somehow do very poorly by the end of twelfth grade? This has policy implications that Minnesota must address.

All of this I believe suggests that, in fact, there are many serious ways in which a careful analysis of the achievement results with an attendant careful analysis of state standards and instruction presented in the classroom does permit serious state level policymaking.

Case Study of Minnesota Mathematics and Science Education: A Synthesis of Interviews with Minnesota Science and Mathematics Educators

Frances Lawrenz

Summary

This case study interviewed people who were involved in science and mathematics education at the State level, the district level, the professional organization level and the classroom level. The report accurately reflects the perceptions of the people interviewed not the author's notion of what was or should have been important in science and mathematics education. The report describes science and mathematics education in Minnesota from the 1960s through the TIMSS testing in 1995.

The science and mathematics curricula had some similarities. Both were affected by the curricular projects of the 1960s and both were, to differing extents, textbook driven. Both had specific topics taught in the high school years for those students who choose to take them. Science curricula had specific topics, life, earth and physical science, taught in 7th, 8th and 9th grades, respectively, that were required of all students. The science content was much less specific in the elementary school. Specific mathematics content was taught in the early elementary grades, but by the middle grades and high school, mathematics classes were tracked with different students receiving different content. Science curricula at all grades changed over the years to be more "real world" but was consistent in its insistence on hands on activities. Mathematics curricula experienced pendulum swings between inquiry, manipulative based approaches to a "back to basics" orientation.

Instruction in mathematics and science differed. Science instruction generally included activity or laboratory aspects, especially at the middle and high school level. Although science instruction at the elementary school level was quite individualized, it was often

kit based and emphasized process skills rather than specific science content. Mathematics instruction was exemplified by the teacher presenting the new topic for the day, working some problems that related to the new topic and then having the students work individually on problems from the textbook or a worksheet.

Science and mathematics were also assessed differently. Mathematics was assessed statewide in several testing programs while science was only assessed statewide sporadically. Testing in neither subject was truly high stakes. Although classroom assessment in both areas was generally textbook based, it was especially so in mathematics. Since science teachers often brought in additional content and since they used laboratories, their assessments were more likely to be teacher constructed. Most assessment in elementary school science was based on participation.

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Statewide influences were much the same for mathematics and science. These influences included the various editions of state guidelines, called Essential Learner Outcome documents, initiatives from the state, the State Department of Children, Families and Learning, certification requirements, professional development opportunities, and the general culture of the state. The state had provided some guidance in terms of frameworks but because of the highly independent nature of the school districts, these were most often advisory rather than compulsory.

The State Department was very supportive of science and mathematics instruction through the state specialists and through its support of SCIMATH MN after 1992. There were numerous professional development opportunities provided by the State Department, professional organizations, and the various colleges and universities. The culture of the state was very supportive of education, including strong support from businesses. The only large difference between science and mathematics appeared to be in the extraordinary opportunity the State provided for environmental education in various settings in addition to the classrooms.

Several explanations were advanced to account for the differences in performance of Minnesota students on the TIMSS science and mathematics tests. These included differences in the nature of science and mathematics content as presented to the students, differences in instructional approaches, differences in the relationships between the TIMSS test and the Minnesota context, and differences in external pressure on science and mathematics education.

Introduction

This report was based on interviews with several people and perusal of the few documents they mentioned pertaining to the history of science and mathematics education in the State of Minnesota. The intent of this case study was to interview people who were involved in science and mathematics education at the State level, the district level, the professional organization level and the classroom level. Often people interviewed had perspectives related to several levels. The interviewees were asked to describe the recent history of science and/or mathematics education in Minnesota; the types of curriculum, instruction and assessment that were used and how they changed (or didn't change) over time; any formal procedures, policies, frameworks, laws, guidelines, etc. that affected science and mathematics education; and then to speculate on why there were differences in the relative performance of Minnesota students in science and mathematics on the TIMSS. Suggestions for interviewees were obtained from SCIMATH MN and then from interviewees themselves.

The process followed in preparing this report was designed to guarantee that the report accurately reflected the perceptions of the people interviewed not the author's notion of what was or should have been important in science and mathematics education. The procedure was to conduct open-ended interviews and to write down all comments made. The comments were then typed into an appropriate section. Transcription took place very soon after the interview so that the conversation was fresh. As the different interviews were being typed, similar comments were grouped together within the sections. When the bulk of the interviews had been completed, the comments were organized into a coherent description of science and mathematics education from the 1960s through the TIMSS testing in 1995. Some events, which took place after then, were also mentioned. Every attempt was made to capture the spirit, intent and wording (whenever possible) of the original comments throughout the reorganization of the report. This preliminary draft was then shared with the state specialists for mathematics and science to obtain their comments and input. A final draft was then prepared to be shared at the meeting of the National Education Goals Panel project group. This final draft was also shared with the state specialists in science and mathematics and the director of SCIMATH MN for any additional comments. After the National Education Goals Panel project group meeting, the final version of the report was prepared and submitted.

Curriculum

Science

There were many important influences on Minnesota's science curriculum: the 1960s National Science Foundation (NSF) funded curricula and related professional development; 1960s and 1990s elementary school science kit projects; the Science, Technology and Society (STS) movement; the interest and focus on contextualization and applications of science; the availability of laboratory facilities in nearly all junior and senior high schools; an acceptance of student collected data being used as a valid part of the pool of data generated by the scientific community (e.g., gathering and sharing of weather data); and accessibility to technology such as computers, GIS and GPS, and probeware. In addition to these directly related influences, the general context of Minnesota, and in particular its emphasis on informal environmental education, influenced what opportunities students had to learn science.

At the elementary level the curriculum was heavily language arts based combined with either textbook or activity oriented science. Middle schools were in between but closer to the high school because most of the middle school teachers have 7-12 licensure.

Secondary and middle school teachers were very dedicated, content oriented and prided themselves on developing their own curricular materials. Despite the heavy emphasis on texts, all science curricula required/suggested laboratory or hands on activities. Therefore the teachers were forced out of a completely textbook orientation. Science teachers were textbook driven but activity oriented. However, the activities and the textbooks were not necessarily connected.

In Minnesota many of the1960's science curricula were actively used. Many elementary schools had ESS or SCIS kits. There was less interest in the early middle school curricula or the slightly later ISCS (Integrated Science Curriculum Study) although IPS (Investigations in Physical Science) was quite popular initially. High schools used mostly BSCS, Chem Study and PSSC. According to Paul Hurd, an internationally known science educator, these curricula contained more current and scientifically valid content, engaged students in independent "discovery type" investigations, emphasized science's intuitiveness and non authoritarianism, and focused on depth rather than breadth. Hurd goes on to say that often the courses were too difficult for the typical student, the courses were not related to the social world of the students and the courses ignored the role of science in everyday life. Because of these shortcomings and others related to difficulty in implementation, use of these new science curricula faded out after initial interest. However, some of the ideas in the curricula were retained in the new textbooks that came later. Additionally remnants of these curricula stayed around in various formats. In fact, some Minnesota schools still had the original curricular materials available as references. BSCS in particular had a resurgence of popularity in the late 1980s with the new releases of curricula for various levels. Many large-scale 1990s projects that gave students a role in learning through global and local data collection and analysis, such as Journey North, GLOBE, Monarchs in the Classroom and the Rivers Project, were embraced by Minnesota teachers.

The high school science curriculum had always been the layer cake approach that it is now, with biology, chemistry and then physics. Many schools offered other electives, such as ecology, astronomy or applied science. Occasionally agriculture or technology classes were allowed as science credits. The movements in the 1970s toward more, open-ended, less "cookbook" laboratory activities affected the high school curricula. Since then there has been some movement toward more conceptually oriented and more contextualized curricula. Although physics was generally more mathematical, there was a push in Minnesota for conceptual, contextualized physics. For example, one physics teacher developed a contextually based physics program that had some impact in the Minneapolis school district and through Minnesota Science Teachers Association. Her contextual physics was designed to help students see real world applications of the physics they were learning. She felt it was particularly relevant for minority and disadvantaged students, who were less likely to have parents in science or mathematics careers, and therefore, had no role models to assure them of the eventual usefulness of studying mathematics and science. Early adopters of ChemCom in the 1980s were well supported with training opportunities and were instrumental in spreading the use of this curricula in many districts around the state as an alternative to the traditional chemistry curriculum.

The middle school curriculum underwent an evolutionary process. It began with 7-8th grade science being a series of units on various topics. In the 1970s attention in Minnesota was focused on middle schools and junior highs. Middle schools were supposed to teach science each year and junior highs were supposed to teach 1 year and 2 semesters of science. Although middle schools were supposed to teach science each year, as more and more middle schools developed, the other subject area teachers lobbied to have their subjects taught as well. Therefore science was not really taught every year and in reality the middle school pattern was much more like the junior high school pattern. Around 1995 the movement in middle school science was toward more integrated and interdisciplinary approaches, sometimes organized around themes. Middle school teachers also moved toward contextual, real world applications for their students with the acknowledgement that many of their students would not be taking science past 9th or 10th grade. These real world experiences were often environmentally focused in both life and earth science.

A consensus emerged within the teaching profession to teach earth science in the 8th grade. This arose, in part, because a state science specialist had been an earth science teacher and was influential in advocating for the subject within the Minnesota Science Teachers Association (MSTA). Through his efforts and consensus building, most science teachers became convinced that it was logical to teach earth science at the 8th grade. The logic was based on the following premises: most students would be taking biology in grade 10, and few students would go on to take chemistry or physics. If few would go on to chemistry and physics, it made sense to place a physical science class at the 9th grade level. If most students would take biology in grade 10, it made sense to place a prior life science class as far away as possible, i.e., 7th grade. This left 8th grade open. Most science teachers came to agree that this would be a good place for earth science. This was probably true as early as the late 1950s.

An earth science curriculum available in the 1960s had some influence but was adopted in only a limited number of schools. However, an active group of earth science teachers continued to build support for a course that would be required of all students in junior high or middle school. State certification policy, which required separate certification for earth science for grades 7 – 12, led many prospective teachers to acquire broad subject area knowledge in earth science. These efforts were aided by the availability of high quality geology courses, particularly at the University of Minnesota and Macalester College, that emphasized inquiry-based and hands-on learning.

The movement toward more contextualized science in relation to physics was actually true for science textbooks at all grade levels. Science textbooks across the board have embraced a more real world approach, along with emphasizing Science, Technology and Society (STS) issues. Although contextualization and STS were somewhat different ideas, they were similar in their intent to make science more relevant to students and hence a more appealing subject to study. An example would be the high school program Chem Com (Chemistry and Community) which was fairly popular in Minnesota.

Along with the movement for contextualization and STS, there was a push to include technology. Science classrooms changing from no computers to one computer to completely computerized science laboratories exemplified this trend. Although more computerization took place in the high schools, it was evident at all levels.

Mathematics

The mathematics curriculum in Minnesota was and continues to be textbook based. However, its history was characterized by more fluctuation between the approaches used than was the case in science curricula. These pendulum swings related mostly to the philosophy behind the curricula being used, because, despite the philosophical swings, the actual delivery of instruction in the classroom remained fairly stable.

The major movements in science were more incremental and cumulative, adding to and refining an existing approach. In mathematics the major movements were more pendulum-like, with the curriculum moving in one direction and then back into another. There were a series of movements toward more inquiry, manipulative based, problem solving mathematics curricula. Most were followed by a backlash of "back to basics" where parents and ultimately school boards called for mathematics to be taught the way it always had been, which meant an emphasis on arithmetic.

As was the case with science, there were several new mathematics curricula developed in the 1960s. One of the more popular mathematics curricula was SMSG. This was used for a period of time but then abandoned by most schools although there were some schools in Minnesota that still used it. This curriculum, like most of the curricula of the 1960s, was quite rigorous, very concept based and very different from what most parents had studied. It had also been developed with only minimal attention to how to help teachers implement it in their classrooms or to how to maintain the materials necessary. There was professional development that accompanied the program, but once the teachers were in their classrooms they were on their own to try and maintain the implementation. This program produced conflict nationwide, which contributed to the "back to basics" movement. Minnesota did not swing so far back to the basics as some other places, but it was still affected.

Since the mathematics curriculum tends to be textbook driven, and the textbooks promoted a "back to basics" philosophy, Minnesota schools reflected that as well. A "back to basics" movement occurred again in the 1990s, and many schools in Minnesota were using texts resulting from this movement.

In the 1960-70s Minnesota was a leader in mathematics education. It had a large grant, MinneMast, to develop mathematics curricula and this brought many highly qualified mathematics educators into the State. There was a strong mathematics department at the University of Minnesota with large numbers of graduate students. Many of these were in-service teachers and many became professors at other colleges throughout the state. Several mathematics education seminars were held with standing room only. This well educated leadership contributed to a strong professional organization, Minnesota Council of Teachers of Mathematics (MCTM).

The presence of strong mathematics educators helped to moderate the "back to basics" movements. The state leaders were forward-looking and personally effective at promoting rigorous, concept based mathematics education. There was a coherent message of what was important in mathematics education. There was also curricular leadership at district levels. There were real leaders with supportive personalities who would follow through and provide encouragement (training, money, acknowledgement, etc) for teachers who worked with them. This led to a leader cadre of mathematics teachers.

The mathematics curriculum was textbook driven, and the selection processes sometimes worked to find the best of the texts that were available. At times, however, the process resulted in texts that were the easiest to teach from. This seemed especially true in smaller schools or districts where one teacher is responsible for teaching several different mathematics classes.

Many teachers supplemented their texts with additional materials. The curriculum before the 1989 NCTM Standards, and the earlier Agenda for Action, generally included computational practice but with a positive bent and with some geometry. Many teachers in the State attended or provided sessions on problem solving, tessellation, calculators, etc. The selection of different texts and the use of supplemental material resulted in quite varied mathematics curricula across the state. Over the years there was also involvement in some of the more innovative curricula such as the Chicago Project. Many primary teachers used "Math their Way" which had a hands-on emphasis.

In the Minneapolis school district, there was strong Title 1 funding. This was used to produce strong mathematics programs at many schools during the 1980s. Many of the "needy" schools provided excellent mathematics learning opportunities such as one-to-one tutoring, mathematics laboratories and computer laboratories. There were also monthly meetings for Title 1 teachers to plan and discuss curricula, which provided excellent professional development. When the Agenda for Action and the Standards came out, there were some classes in Minneapolis that were actually close to those ideals.

Along with the pendulum swings in curricular approaches, was a somewhat more continuously forward movement toward calculator/computer assisted mathematics, although even this trend experienced ebb and flow of public acceptance. Mathematics educators endorsed calculators but many parents would say, "But Johnny can't add and subtract." Minnesota mathematics curriculum was involved with calculators for a long time. For example, even in the early 1970s some schools had Hewlett Packard teletypes with a program to provide individual worksheets for students.

Minnesota was ahead of the curve in mathematics early on and then fell back, perhaps because it was too complacent. It was moving forward again with all the new curricular initiatives related to the NCTM Standards. In the 1990s project Prime was designed to help spread word about the Standards. There was a focus of attention on the Standards and the professional organizations were promoting them through workshops and at professional meetings. The author of "Everybody Counts", which provides a rationale for the NCTM Standards, was from Minnesota, so the NCTM Standards were readily accepted. Following the publication of the "Agenda for Action" and the Standards, the pace of change was slow. The teachers were informed and aware but this didn't necessarily translate into different instructional practices. There were very few curricula that were matched to the NCTM Standards when they came out in 1989, so teachers struggled with how to implement them. The new Standards based curricula were only just becoming available in 1995 so at the time that TIMSS was administered the typical middle mathematics curriculum would have been 80% algorithmic and 20% conceptual.

Instruction

Science

Generally the instruction in science was textbook driven like the curriculum, but activity oriented. Science teaching in Minnesota has a tradition of hands on approaches. It may not be systemic but certainly predominant. There is an interest in and recognition of the need for content based pedagogical knowledge. Most science teachers believe they should provide hands-on activities. Unfortunately the textbook concepts and the activities are not always connected, nor are the activities necessarily tied to substantial science content. There is an activity base but not necessarily connected to true meaning. Additionally the activities are often quite structured or "cookbook-like."

Minnesota had a long tradition of instruction in science that was geared toward reaching agreed upon outcomes or standards. The process was incremental but cumulative. There was activity-based science in Minnesota even before it was promoted by the professional journals, such as those from National Science Teachers Association (NSTA). There seemed to be a consensus of opinion about what constituted good science teaching among classroom teachers, college science education people and state officials. There were different mechanisms for providing instructional help and training, but the message was consistent. Minnesota had strong leadership at many levels in science instruction. Individuals from some of the larger districts, staff from higher education, and staff at the

State Department worked collaboratively to advance the ideas of "doing science" as a method for students to develop understanding. There were many opportunities for professional development in the form of courses, workshops and institutes.

Minnesota was a national leader in activity-based elementary school science. The prevailing philosophy was the more experiences and the earlier, the better. The instructors at the elementary school level made some use of instructional kits, but by the late 1970s the elementary school teachers were back to using books, teaching a few of the older kit-based lessons they liked, or not teaching science. The belief that science should be activity oriented however stayed. This feeling was encouraged by a series of grant projects that were supportive of hands on (usually kit-based) inquiry oriented science. In the 1980s the new wave of science curricula was available and were commercially marketed. FOSS marketing was especially strong and approximately 40% of the districts have FOSS kits. In addition an NSF project to disseminate science kits through the State's educational service areas was active in providing many smaller districts with kit based elementary school science materials.

There was less input into instruction at the junior and high school levels although the consistent message of hands-on inquiry was evident there as well. The consensus opinion was enhanced because of the older population of teachers available in Minnesota. These more experienced teachers knew their content and how to relate to the students, and they mentored the newer teachers to help them develop this balance. At these levels, science teaching began as rote learning but became more discovery oriented. By 1995 instruction was still textbook based but often greatly enhanced by teachers. Teachers tended to use references and more inquiry; letting students evaluate things on their own. Minnesota high school and middle school teachers are well qualified. Many held master's degrees and Ph.D.'s. Relative to many states, Minnesota had few teachers teaching out of their field and even fewer non-licensed individuals in the classroom.

Mathematics

In mathematics the content of instruction was mixed depending on which part of the "new curriculum--back to basics" cycle a particular district or school was experiencing. There was also mixed content because of the tracked classes. Although tracking provided some slight differences in instruction, the main difference was in content, with more material covered in less time in accelerated classes. The general pattern of instruction throughout the swings was: review yesterday's work, present the new material and then have the students work individually with teacher assistance on problems directly related to the new work. The instruction around 1995 was more problem solving oriented than 20 years ago because the students were more sophisticated and because of calculators and computers. At first the mathematics instruction was more behavioral (in keeping with the emphasis at the time in psychology), but recently had a slightly more gestalt, constructivist tone. Despite this most classes were as described above.

Overall the Minnesota high school and middle school mathematics teachers were very well qualified. Teachers were very well prepared both in terms of pedagogy rooted in activity based learning and because more mathematics content was required for licensure. National Assessment of Educational Progress (NAEP) assessments in the 1990s showed that Minnesota had the highest percentage of 8th graders taught mathematics by teachers with a mathematics or mathematics education major. Minnesota elementary school teachers were just as poorly prepared as teachers in other states, because only one or two semesters of mathematics were required for Minnesota K-6 licensure. Although many teachers were "tellers", many of the "tellers" tried to make mathematics as interesting as possible. They were good algorithmic teachers, and they were moving toward the broader issues defined by the NCTM Standards. The notions of inquiry and teaching for understanding were difficult for them, mostly because they were never taught this way nor trained to teach this way.

One attitude that underlay instruction was that many mathematics teachers believed that some students are innately gifted mathematically and that some students just will never be able to understand mathematics. This attitude supported the worst sort of tracking and could truly prevent students from understanding mathematics.

There were strong ties in Minnesota among mathematics teachers at all levels and especially between high school and college mathematicians. The Minnesota Mathematics Mobilization group was an example of these strong ties. This had a synergistic effect. There was strong undergraduate mathematics instruction because the incoming high school students had strong traditional mathematics backgrounds. The college experience produced strong high school teachers, which in turn produced strong high school students to repeat the cycle.

Assessment

Science

There was very little emphasis on science assessment at the state level. There were a few attempts at statewide assessment but none of it high stakes. There was an early attempt to have the statewide assessment measure process skills as favored in the 1960s curricula. After that, however, the state science assessment became more multiple choice oriented. In the early 1990s there was an another attempt to include a hands-on, performance-testing component, but soon after that, statewide assessment in all disciplines was suspended. The several attempts to develop state science testing always involved excellent teachers from around the State. Even if the tests were not critical in and of themselves, the test development sessions provided excellent workshops and intellectual stimulation for the teachers involved. Additionally the administration and discussion of these tests helped to develop consensus around what was important in science.

In the middle and high school classrooms science assessment was at first simple questions related to memory and rote learning. Over time the tests became less structured and more problem based. Simultaneously there were elements of performance assessment because of the laboratory work, although not in the sophisticated fashion available today. The Advanced Placement (AP) courses and various national science society tests helped to mold high school and, ultimately, middle school assessments. At the elementary school level science assessments were designed more to encourage students to engage in scientific processes than to assess student understanding. At no levels were there concerted efforts to use assessment results to improve teaching or to diagnose student difficulties.

Mathematics

There was continuous state- or district-wide testing of some type in mathematics but none of it was truly high stakes. Initially in mathematics the students were tested using the Iowa or California tests of basic skills which were targeted toward arithmetic skills. Following that there was a new state test developed that included more problem solving items. For this test and other state-developed tests, the state involved teachers in the selection and review of items. The state test was more progressive than the basic skills tests, but taking it was optional.

In terms of classroom testing, the proliferation of AP and International Baccalaureate (IB) programs with their subsequent testing affected all of the assessments. The AP and IB tests were well designed and required more in-depth reasoning. This testing pushed some of the mathematics content down to the early high school and middle school grades and helped to define mathematics. There was also a special testing and instructional program at the University of Minnesota mathematics department for talented mathematics students. This program hired high school teachers so they (and their regular students) benefited from the contact with mathematicians and new teaching ideas as well.

There was also a growth of participation in the Mathematics League competition. This helped to bring national movements in mathematics to the attention of Minnesota educators and built a spirit of friendly competition in mathematics.

Generally mathematics assessment results were shared with communities. People knew what was going on and cared about it. Therefore, they kept up the pressure to do well. Most districts did some sort of standardized testing and tracked achievement from year to year. Curricular leaders attempted to make sense of the results and made decisions on what to do to address weak areas. Around 1995 it seemed less apparent that leaders were accepting this responsibility although this may change with the new testing programs and the increased emphasis on accountability.

State-Wide Influences

State Curriculum Guidelines

The first science and mathematics guidelines were developed in the early 1970s. They were less sophisticated than the frameworks of today, more loosely worded and difficult to directly assess. Teachers were required to spend time developing them and thinking about them. These were called Essential Learner Outcomes (ELO) and provided guidelines for districts to use in developing curriculum. The mathematics guidelines were ungraded lists of outcomes that were not as useful as they could have been in helping teachers determine what to teach. The science guidelines were ambitious ideals for the coverage of science content. Teachers did not necessarily feel that they could actually do all these things in their classrooms. These documents did not prioritize among the various content. Most things were considered equally important. There were also guidelines, which specified things such as what should be in a building for science room plans, and number of minutes to teach science, but it was not an official policy. The most recent science and mathematics frameworks and outcomes were built on these early efforts.

From 1966 to 1979 David Dye at the State Department of Education published the Mathematics Flyer. This was an interesting newsletter with announcements about programs, events of interest to mathematics teachers, ideas on improving teaching and a BrainTeaser, which was answered in the next newsletter. These Flyers reflected the changing national scene of mathematics education and provided direct access to those issues to teachers in Minnesota.

Department of Children, Families and Learning

The State Legislature was continuously supportive of education through its appropriations to the Department of Children, Families and Learning. (Minnesota combined its agencies dealing with education and many social services into a single department.) The Department has shown its commitment to science and mathematics by providing consistent funding for State science and mathematics specialists even when the specialist positions for most other subject areas were cut. Furthermore, the people in these specialist positions have been quite influential in shaping science and mathematics education in the State. These specialists had extensive engagement with the top science and mathematics teachers in the state, thereby guaranteeing teacher involvement in what the state did in science and mathematics.

Legislators worked streamline legislation and to reduce mandates and statues that worked at cross-purposes. Therefore there were fewer "loopholes" and teachers and schools were "forced" in the directions the science and mathematics specialists thought were most beneficial.

The Department supported SCIMATH MN, which was a powerful force for excellence and innovation in science and mathematics education. Additionally through SCIMATH MN and the Department of Children Families and Learning there was a large investment in professional development.

Certification Requirements

The science and mathematics certification requirements have had significant impact. High school teachers were required to have significant amounts of content area coursework in addition to methodology classes. Most middle school and high school teachers were certified in their respective areas and therefore had very strong content backgrounds. Although not many elementary teachers specialized in science or mathematics, specialized methods courses were offered and preservice teachers were required to take at least some mathematics and science courses. Both MSTA and MCTM have been actively involved in certification discussions and have advocated for rigorous certification requirements. Perhaps because of the high certification requirements, Minnesota also paid its teachers fairly well. This may have led to the comparatively stable teaching force and the relatively high numbers of male teachers in both mathematics and science.

Professional Development

Significant amounts of professional development were provided by the State Department of Children, Families and Learning, SCI MATH MN, MSTA, MCTM, and the various colleges and Universities throughout the State. One example is the "road show" in 1988-89 in response to the new requirements for laboratory safety. These sessions brought many teachers together and helped them to rethink their curriculum especially in chemistry. A mathematics example was PRIME, which took place starting in 1991. There has been a wide range of offerings supported by the Eisenhower funds both at the local district and higher education levels—a veritable collage of professional development opportunities.

Both MSTA and MCTM are powerful organizations and their semi-annual conferences, special interest groups, newsletters, etc., provide support for interested teachers. The organizations provided the opportunity to be with colleagues who were active and cared about science or mathematics instruction even if other teachers in the home school did not.

MSTA sponsored many sessions with elementary school teachers in its attempt to get teachers to "do" science. These elementary school science workshops were generally funded by Eisenhower money. Unfortunately (or maybe fortunately for broader exposure) different teachers attended each year. One outcome of this was a tremendous growth of elementary school teachers in MSTA from 50 out of 600 in1987 to 700 out of 1400 recently.

Nationally MCTM was one of the strongest state mathematics education organizations. It has been in place since 1949 and has had continuous annual conferences. It had a series of strong presidents providing a basis for leadership in mathematics education in the State. In the 1970s and earlier the MCTM leaders were reform minded and forward looking. In the 1990s NCTM and MCTM were closely aligned. Many leaders in the state attended the NCTM meetings and then return to share their knowledge with others in MCTM. Minnesota teachers were well informed about what was going on nationally.

Culture of the State

Minnesota was and continues to be a strong local control and local choice State. It was and is very populist and the whole notion of standards challenged its sense of independent choice. Parents and other community members emphasized the importance of education and were interested, concerned and vocal about what should go on.

Minnesota had a comprehensive system of higher education. There were many public and private institutions available. Most colleges and universities have had strong science, mathematics and education departments. These departments nurtured the development of many national and local leaders and provided a fertile field for implementation of innovation in science and mathematics education. There were strong leaders in key places that worked on reform. There were also strong links between colleges and K-12 systems especially in mathematics.

The culture of Minnesota is supportive of education. People want and expect students to do well. They try to follow the current research and make appropriate changes. There is active business and industry support for rigorous science and mathematics education. There is a tradition of strong parental investment and lots of extra curricular activities. One of the strongest areas was in the environmental sciences. There were a multitude of environmental learning centers, nature centers, day use and residential environmental centers, state parks with interpretive programs, etc. as well as science museums. The Science Museum has had a statewide effect though its outreach programs as well as its displays. There was also a strong interest in science displayed in the media, both in print and through television programs such as Bill Nye and Newton's Apple.

Potential Explanations For The Differences In Science And Mathematics Performance

Relationships between the TIMSS Tests and the Minnesota Context

The TIMSS science tests were better matched to the material taught in science than the material taught in mathematics in Minnesota. For example, Minnesota 8th graders had taken earth and life science which fit the TIMSS framework. In contrast 8th grade mathematics in Minnesota with its lack of emphasis on algebra, geometry, measurement, probability and statistics was much less like what was tested in TIMSS. In other words the science content taught in Minnesota schools was closer to that taught internationally than the mathematics content. Furthermore the science content was more similar throughout the State than the mathematics content. Many Minnesota science teachers used the same textbooks and the content in those was matched well to the TIMSS test. The Minnesota mathematics teachers used different texts. This was often because the students were tracked and therefore would be exposed to different content, but also because of the "new curricula-back to basics" pendulum swings. This resulted in much less of a match for all students with what was on the TIMSS mathematics test.

Differences in the Nature of Content

Science, properly taught, could be more developmentally appropriate than mathematics. The match between the mathematics taught and the children's developmental level was not as good as the match between the science taught and the children's developmental level. The hierarchical nature of mathematics, as presented in traditional programs, made it more difficult to learn. The traditional notion is that you had to learn the prior material before you could go on. Because much science was not hierarchical, it could be broken up and different topics taught at different levels. Students could easily have learned some physics topics before some biology ones or have done well in life science and not in physical science. This sort of compartmentalization was much more difficult in traditional mathematics where learning one thing was more dependent on having mastered a previous concept. Therefore, because some of the necessary mathematical content was above the children's developmental level, the children did not understand mathematics as well. Unless they memorized and used algorithms well, they would not do well on mathematics tests. Additionally there was a push to have even more rigorous topics in lower grades, exacerbating the developmental level problem. Furthermore mathematics curricula, especially the "new" curricula, placed a heavy emphasis on reading. This put students who could not read well at a disadvantage.

Although mathematics teachers often reviewed and taught the same topics over and over, this was not in-depth teaching. Each mathematics topic was seen as a tiny, little package not as part of a coherent whole. Therefore what students were taught was fragmented. For example, there was not a concept of area that the students were taught to understand there were sets of formulas, each seemingly separate. There were no big ideas around which they could organize their understanding. Because of this discrete approach, it often seemed that the "train kept going even if the kids didn't get on it." This was in contrast to science, which was organized around several big themes. The science curriculum therefore, in some ways, was more focused than mathematics. Additionally in science, review was often embedded in any new topic because of the interrelated themes.

Different personalities went into science and mathematics. Mathematicians tended to be more theoretical and more likely to be enamored of the beauty of mathematics. Although scientists were like that too, many were also interested in practical applications.

Differences in Instructional Approaches

Minnesota students may have performed better on the TIMSS assessment in science than in mathematics because science was often taught in a more activity based and more meaningful fashion than mathematics. Because of the *de facto* requirement in science for laboratory work, science teachers were encouraged to and often did use hands on activities. Even if the activities were poor, there was at least minimal engagement. In mathematics hands on was thought of as more of a diversion, e.g., "the manipulatives were good but now lets get on to the real math." In mathematics instruction manipulatives were viewed more as a game or extra activity than as a tool, as was the case in science instruction. In mathematics hands on activities often were part of the "new" curricular movements, but because of the pendulum swings with "back to basics" curriculum, there was less opportunity for the development of these types of instructional approaches. Science teachers often used hands-on activities to illustrate a problem. This was not the case in mathematics where the teacher presented how to do a particular type of problem and then the students practiced using that solution. Through the hands-on process students got more reteaching, because the teacher said it, they saw it and they talked to each other about it. Mathematics instruction was often just basic skills or all problem solving and not mixtures of these ideas. Science was better balanced among textbook, laboratory and group work.

As taught, science had a real touch and feel with the world; it was very concrete. Mathematics was more abstract. Science could seem more exciting. Mathematics was more memorizing; science more doing. The way science was taught was inherently more real world than mathematics. The tradition in mathematics was rote learning with little context. Mathematics teachers were less likely to make real world connections or to demonstrate why mathematics might be useful. Therefore fewer students might have been engaged and fewer learned well. Because science was more contextualized, there was more opportunity to learn some science outside of the classroom than mathematics through newspapers, environmental discussions, TV shows, etc.

Tracking in mathematics kept some students forever behind. Additionally as teachers became adjusted to lower track classes, they may have lowered their standards so that even if they were teaching a more advanced class, they expected less. Mathematics was often tracked because people believed they knew who could and couldn't do mathematics. As a result not all students got to study all concepts. Lots of students just kept retaking elementary mathematics topics. Because science is not tracked, all students were exposed to all topics in depth until 10^{th} grade when students could opt out of science.

External Pressure

The mathematics curriculum was more affected by parent and community opinion than the science curriculum. All parents had taken mathematics in school and therefore felt more qualified to give advice on how it should be taught. Mathematics was seen as more "high stakes" than science, and parents were more concerned about what was done in mathematics classes. Often this led to less innovation on the part of educators.

Epilogue to NEGP Case Study Of Minnesota 8th Grade TIMSS Results

By Bill Linder-Scholer
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TIMSS has captured broad public attention primarily because of the implied "horse-race" among countries for high rankings on the comparisons of student achievement in science and mathematics. But the TIMSS data--especially the findings relating to what American schools teach and how we teach it--have much more to offer policymakers and educators, particularly in regard to setting state and local standards and guiding related reforms intended to change curriculum, instruction, and assessment in order to improve student learning. This aspect of TIMSS—using the TIMSS data and follow-on analysis to provoke and guide the move toward a standards-led system —has only recently begun to receive appropriate attention by policymakers and others concerned with envisioning statewide standards and systemic reform for K-12 education.

Minnesota's experience with TIMSS is an exemplary case study in this sense, offering a clear and transportable set of conclusions from TIMSS with respect to establishing statewide standards, implementing those standards at the local level, and pushing for improved performance as a result. More specifically, the Minnesota 8th grade TIMSS results illustrate the key TIMSS themes and suggest the powerful improvements in system-wide performance that can come from **high expectations** for all students, **focus and coherence** in curriculum, and **alignment** of the key delivery factors including instruction and assessment. Furthermore, Minnesota's experience with TIMSS provides a framework for ways in which other states and their local education units can use TIMSS to inform policy and practice in the context of content standards and statewide testing.

The State of Minnesota participated in the original (1995) TIMSS testing and survey work at all three TIMSS grade levels [the only state entity to do so] and was oversampled in order to allow comparison of Minnesota results with those of the U.S. as a whole and with the other TIMSS countries. Minnesota's performance on the TIMSS student achievement assessments was generally similar to the overall U.S. performance: strong performance at the 4th grade level relative to the other countries, middling at the 8th grade level in mathematics, and weakest at 12th (final year of secondary school).

First Finding: Consider the International Context

Even in these very general results there is an important first finding relative to setting standards: being among the best in the U.S. is not the same as being among the best in the world. In other words, in a state that had prided itself on the apparent quality of its K-12 math and science education system, it was a bit of a surprise to find that, especially in mathematics, Minnesota students ranked no better than average among the TIMSS countries, and even our top students were only average by world standards. The point from a policy perspective was simply that we clearly had a need to improve, and setting statewide standards was the only likely way to improve across the entire state (the system).

Said another way, the results of TIMSS help make the "case for change" when it comes to considering the need for and potential benefits of statewide standards and assessments. Does the U.S. have to be "first in the world" in every category of TIMSS testing? No, but do we need to do significantly better in order to guarantee a reasonable level of math and science literacy for all our students? Yes, the TIMSS achievement data suggest.

The Minnesota Anomaly

Although Minnesota student performance on TIMSS was like the overall U.S. student performance in many respects, there was an anomaly in the Minnesota scores at the 8th grade level. That anomaly is highly consistent with the major TIMSS findings and offers important pointers for standards-based reform.

The anomaly was simply this: while Minnesota middle school students were, like their U.S. counterparts, mediocre in mathematics, the very same Minnesota 8th grade students scored significantly higher than the U.S. in science, placing among the best in the world in some content areas of science. This outcome is particularly surprising because it cannot be understood or explained away on the basis of who was taking the test, the difference in their backgrounds or socio-economic standing, and so forth—all the reasons we typically turn to first in order to try to understand differences in student performance on a given assessment. Thus, the anomaly in scores itself points to factors in the instructional core, a message of potentially broad application, especially from a state policy-setting perspective.

And as this NEGP case study shows, the apparent explanation for the anomaly in the Minnesota 8th grade TIMSS results is primarily a matter of differences between math and science in terms of system expectations, system focus and coherence, and system alignment. As Bill Schmidt's careful and illuminating analysis of the Minnesota TIMSS data shows, Minnesota's world-class performance in science at grade 8 and correspondingly mediocre performance in mathematics is most likely the result of the following factors:

- No student tracking (and hence uniformly high "expectations" for all students) in science, as compared to rather thorough-going tracking (with curriculum differentiation and thus mixed "expectations" for students) in mathematics;
- A relatively high degree of focus and coherence in the science curriculum up through grades 8 or 9, as compared to a U.S.-like "mile wide inch deep" curriculum in mathematics across the same grades;
- Remarkable alignment of teaching materials, scope and sequence, and instructional strategies on the science side, as compared to the mathematics side.

Again, Minnesota's experience with respect to discovering the ill effects on system performance of having lower expectations for some students in mathematics is essentially a universal U.S. experience. The very tradition and practice of K-12 mathematics education in this country has institutionalized differing expectations, with diminished system performance as one result.

What this Means for Setting State and Local Standards

These findings, though particular to one state, are actually very good news for all policymakers and others engaged in the business of standards-oriented reforms. Good news because the findings do not depend on some "magic bullet" solution such as implementing a particular science curriculum program or simply changing textbooks or teaching strategies. Good news because these findings suggest that significant system performance improvements can be achieved by understanding and adjusting the "expectations" of the system (for example, asking the question, "what do we expect of all students in math and science in our state or district?"); by providing guidance to practitioners on what to teach, to whom, and the most likely effective methods; and by encouraging alignment (not necessarily by heavy-handed, top-down dictation but by encouraging "best practices" and other professional norms that will foster alignment of practice at the local and classroom levels).

In other words, TIMSS has much to say to policymakers and educators regardless of an individual state's or district's goals, because TIMSS speaks to the issues of implicit and explicit system standards, system focus and coherence, and relative alignment among the key components of the education delivery system *whatever that system's goals are.*

Step number one for state policymakers, then, is to consider, and change if appropriate, the implied statewide "expectations" for all students in mathematics and science, especially as judged in an international light. For example, at the very point in time (spring 1997) that Minnesota math and science educators were first pouring over the Minnesota 8th grade TIMSS results and reviewing those results with Bill Schmidt and others involved in the national TIMSS effort, the Minnesota legislature was putting into law the first-ever mandatory statewide test, a basic-skills "high stakes" (passage required for high school graduation) test of elementary-school mathematics. The painful irony, based on what we were just learning from TIMSS, was that this new statewide test that included no algebra and no geometry was committing the State of Minnesota to a less-than-world-class standard (expectation) in the key discipline of mathematics. In fact, the new statewide math test was reinforcing some of the worst aspects of traditional U.S. mathematics education, especially an emphasis on low-level computational skills at the expense of more rigorous problem solving skills. Suffice it to say that Minnesota's basic skills test in math has since been revised (thanks in large part to the influence of TIMSS) to include at least a few of the topics in algebra and geometry that most of the TIMSS countries consider "basic" for their students by the end of 8th grade.

The TIMSS findings relative to "expectations" or curricular intentions are fairly clear, at least in this general sense—if we expect less of our students overall, we'll get less in achievement relative to other countries. And the powerful role that statewide standards or high expectations for all students can play in system performance is clearly illustrated in the Minnesota 8th grade TIMSS story, wherein the statewide expectation that all Minnesota 8th graders take essentially the same science course, with no curriculum differentiation or watering-down for some students, produces significantly greater system performance than does the mixed set of statewide expectations embedded in a highly-tracked program of mathematics education. Add to that the fact that, more by practitioner consensus than by statewide design, Minnesota had achieved a remarkable degree of focus and coherence in its science education program through grade 8, and alignment of other key delivery factors, as noted in the case study.

The question of how to apply such findings in diverse education environments around the country points to another one of the extraordinary benefits of TIMSS--that it works well within any given system and at all levels in the education system. The questions that TIMSS helps us uncover—about expectations, about focus and coherence, about alignment—work equally well at the state, district, or even building levels. Thus, even though a given district may not be able to do much about changing the state requirements it works under, district leadership can do a great deal about setting expectations at the district level. And the reality of the standards movement to this point in time is that state standards are still generally so broad in most state settings that districts continue to bear the burden of translating those broadly described state learning goals into district-level expectations, a focused curriculum that is coherently arranged by scope and sequence, and so forth. TIMSS should be a district's best friend for any district-wide or even building-wide review of mathematics or science program goals, means, and outcomes.

TIMSS Provides Baseline Data for Standards-Based Reforms

It's no accident that use of TIMSS data—both student achievement scores and the contextual data covering curriculum, instruction, and school environments—fits naturally and helpfully into district- or school-based continuous improvement environments. TIMSS afterall was intentionally a look at *system* performance and differences among many countries and many different types of educational delivery schemes. So, after years of having comparative data on student achievement differences but few clues about *why* performance might differ from system to system, TIMSS now gives us an extraordinary set of data on how countries differ in what really matters—that is, how they differ in what they teach, to whom, how they teach it, and how they assess it.

This brings us to another powerful use of TIMSS in defining and driving standards-based math and science education reform: for the first time ever, we have relevant and reliable data that lets us compare curriculum, instruction, and schooling among forty-plus countries, including some countries whose approach to schooling is worth considering to see alternatives to our own approaches. And here again, the Minnesota experience suggests the transferability of the use of TIMSS as a benchmarking and continuous improvement tool.

Over time, Minnesota's approach to using TIMSS to stimulate and guide standards-based reform is gradually shifting from the state level applications (questions about "expectations" as expressed in statewide standards and tests) to district and local applications, where the questions of what to teach and how to teach it are finally and precisely decided. Thus, for example, districts going through a systematic program review, for the purpose of instituting a standards-based math or science program K-12, can turn to the TIMSS data to ask: "What does TIMSS say about curriculum?" or "What does TIMSS say about instructional practice?"

A district (or school) interested in making standards-oriented changes in its K-12 mathematics program will, as even the casual reader of TIMSS can see, find many specific and helpful questions to pursue: What do we mean by curriculum? How does our current district practice on tracking and time spent on mathematics compare with the international averages (and what should we do about those differences, especially as they relate to our specific district learning goals)? What's the structure of our district curriculum, and do we have the kind of focus and coherence we want and need? And so forth. The TIMSS reports for the various grade levels, especially for grades 4 and 8, contain a wealth of data on these and related questions. And tools to help districts use TIMSS for diagnostic purposes now exist [see the U.S. Department of Education's TIMSS "tool kit" or the National Research Council publication called "Global Perspectives for Local Action: Using TIMSS to Improve U.S. Mathematics and Science Education; a Professional Development Guide," Academy Press. Washington, DC 1999].

But even in the matter of science, where the U.S. does relatively better as compared to mathematics, TIMSS can serve as a helpful tool for analysis of current practice and as baseline data for judging a state's or a district's or a school's progress toward a vision of standards-based science (or mathematics) education. For example, from the TIMSS data Minnesota science educators discovered that although Minnesota 8th grade science scores on TIMSS were quite high, the reality of what goes on in Minnesota middle school science classrooms still lags far behind the vision that this state has for its science education programs statewide, as described in recently adopted (1998) statewide content standards. One specific example drawn from the Minnesota TIMSS data will illustrate its diagnostic potential: *Half of Minnesota 8th grade students report that they always begin a new topic in science with the teacher explaining the rules and definitions.* This fact can be used to stimulate discussions with teachers about the nature of their current practice, about how an inquiry-based class might begin, and how to move from current practice to envisioned practice. Said another way, TIMSS helps ask the question: "So now that we have a hands-on science education program, how do we move to "minds-on" as well, and how will we know that we're getting there?"

One of the most promising discoveries in the Minnesota 8th grade TIMSS anomaly mentioned earlier is that the world-class student achievement scores were the result of a set of system factors that were determined not by state policy but by teachers themselves, working on shared goals and building up a set of norms or expectations for science education which had powerful system results. In other words, even in situations where statewide standards are not achievable or likely to happen anytime soon, practitioners in the system can make a significant difference in system performance by virtue of common beliefs, attitudes, and practices relating to curriculum, instruction, and assumptions about what students can learn and who can learn what.

Finally, What TIMSS Cannot Do for Standards

What cautions might emerge from Minnesota's experience with TIMSS, especially relative to establishing and implementing a standards-led statewide system for K-12 math and science education?

For starters, it is all too easy to over-sell TIMSS as a test. It is, of course, the test-score horse-race factor that gives TIMSS its unusual ability to capture public and media attention, not a bad goal in itself. And benchmarking student performance against international standards is also an important goal, as already noted. In fact, there are now several states—working with the national organization, Achieve--with plans to directly import test items from the TIMSS assessments into their statewide tests, to provide international benchmarking capability. But in the end, its likely that the TIMSS contextual data, not the comparative achievement scores, will be most useful to states and localities in transforming their math and science programs in the image of a standards-led system.

The Minnesota experience in this regard is as follows: TIMSS provided a needed wakeup call and will continue to provide relevant baseline data on our progress, via continuous improvement planning, toward our vision of standards-based math and science. But in the same breath, we also realized that the TIMSS test items, based as they were on an international lowest-common-denominator curriculum, are *not* necessarily the most appropriate test items by which we should judge Minnesota's progress toward its own vision and standards. In fact, that's one of the most important but least understood findings from TIMSS—the importance of aligning assessment (whether it's a statewide test, a district test, or a classroom assessment activity) with the particular learning goals that tool is intended to assess.

Then, too, TIMSS used in the wrong ways may contribute to the "mile wide, inch deep" problems with the U.S. curriculum by seeming to suggest more stuff to be covered, more activities to be attempted, more tests to be given, and so forth. Policymakers can unwittingly contribute to that traditional U.S. problem by continually moving the target ("what will the standards be this year?") or by failing to give districts and schools the authority to stop doing things as well as the mandate to do other things. But the key TIMSS themes—high expectations, focus and coherence, and system alignment—keep bringing us back to the tough (but helpful) questions about what mathematics and science education should and shouldn't be.

###

"TIMSS and the Standards: Ways to Use TIMSS to Advocate for Standards-Based Math and Science Education"

- TIMMS provides support for grounding state standards in common vision (e.g., national math and science standards)
- For influencing the design and deployment of statewide tests
- For guiding development of state curricular standards and frameworks
- For training leadership cadre and statewide leadership infrastructure
- For providing data-based approaches to decision-making on local curriculum, instruction, and support schemes
- For guiding professional development practice
- For establishing a "baseline" on current practice and for benchmarking current practice against world norms
- For linking K-12 practice with needed reforms in math and science teacher preparation and development
- For reaching parents and engaging them in support of standards-based math and science education

APPENDIX

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