What Seems to be Happening in Mathematics Lessons? Findings from one School System and Five Student Teachers

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The Third International Mathematics and Science Study (TIMSS) includes indicators of classroom activity as well as student achievement (United States Department of Education, 1996). TIMSS is considered by some to paint a disturbing picture of the intellectual climate in typical eighth grade mathematics lessons in the United States (Forgione, 1996). Forgione states:

> Despite reform recommendations and standards that call for students to apply mathematical thinking, the study shows we teach students how to do something, not how to understand mathematical concepts…. 95 percent of math teachers…reported familiarity with the education standards developed by the National Council of Teachers of Mathematics…. Yet analyses of videotaped lessons show that few apply key points in their classrooms. (p. 2)

The authors interpret Forgione as being concerned that procedural knowledge is emphasized in mathematics classrooms in the United States at the expense of conceptual knowledge. The *Standards* of the National Council of Teachers of Mathematics (NCTM, 1989) referenced by Forgione call for a *balance* of procedural and conceptual knowledge so that students gain mathematical power.

> We are convinced that if students are exposed to the kinds of experiences outlined in the Standards they will gain mathematical power. This term denotes an individual's abilities to explore, conjecture, and reason logically as well as the ability to use a variety of mathematical methods effectively to solve non routine problems. This notion is based on the recognition of mathematics as more than a collection of concepts and skills to be mastered; it includes methods of investigating and reasoning, means of communication, and notions of context. (p. 5)

Historically, a *balance* of concepts and skills in the mathematics student's experience was a hallmark of the career of the late William J. Brownell—an advocate of making mathematics meaningful to students. Such balance is the focus of one of his best-remembered works entitled: Meaning and Skill—Maintaining the Balance (Brownell, 1956/1987).

The NCTM *Standards* (1989) portray concepts and skills as necessary components of mathematical activity (p. 7). Mathematical activity extends into investigations and calls for communication and reasoning in solving problems. A sound mathematics program, and certainly a program for citizens of the 21st century, engages students in mathematical activity. Mathematical activity is a likely casualty when students are in school programs characterized as teaching "students how to do something, not how to understand mathematical concepts" (Forgione, 1996, p. 2).

TIMSS gathered information from classrooms across the United States. Classroom data, however, was not categorized or quantified relative to conceptual and procedural knowledge or mathematical activity. In responding to a request from a school system, we decided to attempt a report of student behavior across all grade levels. We attempted to gather and consider data to provide evidence to assist in addressing the following research questions for a particular school system:

1. What is the amount of attention given to various kinds of activities and how are students called upon

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to process information in typical mathematics lessons?

2. Does this attention indicate a balanced program with respect to procedural knowledge, conceptual knowledge, and mathematical activity?

Forgione notes the TIMSS study found that while 95% of practicing mathematics teachers reported familiarity with the recommendations of the NCTM Standards (although it is not clear what "familiarity" encompasses), few apply them in their classrooms. Are there elements in the workplace that mitigate against the application of the Standards? If so, perhaps these elements have not had the opportunity to fully inhibit beginning teachers. To tentatively address this conjecture we availed ourselves of the opportunity to gather data from the lessons of five preservice student teachers and to also address questions 1 and 2 above relative to this small population of student teachers in secondary school mathematics.

In January of 1996 the school system under investigation called upon the authors to study its mathematics program. Leaders and teachers in this system were concerned with students' mathematics performance on both national standardized tests and state norm referenced tests. Students' reading scores were deemed satisfactory. Students' mathematics scores were considerably below state and national averages for both peer and neighboring systems in the state, and well below similar sized systems across the nation having approximately the same percentage of students on free or reduced lunch. This rural system had one high school, two middle schools, four schools with students in grades 2-5, and one large complex for students in grades K-1.

To encourage teachers to keep to their regular lesson formats teachers were made aware that we were committed to gathering data on student activity, and that individual classrooms would not be studied or identified. Reports of the findings were to be made available to all teachers and administrators in the system. Classrooms were visited and data gathered over a two-month period—three days in March and two days in April of 1996. TIMSS results were first reported in November 1996.

Student Actions

In tabular form below we share the findings of fifty days of observation in one Georgia school system with an aggregate of approximately 5,000 students. This represents what ten observers recorded in five days over a two-month period. Students' classroom activity was tallied each minute by experienced classroom teachers, mathematics supervisors, and college level mathematics educators—supervisors and college mathematics educators all having at least three years of K-12 teaching experience. To represent each of the grade level clusters, one hundred and twenty-two lessons were observed on a random basis. Inter-rater agreement on eight pairs of observers was 91%. Inter-rater agreement was calculated by assigning a pair of observers to the same lesson and dividing the number of minutes of agreed categorizations in these eight lessons by the total number of minutes the pairs of observers worked together.

The student behavior categories were identified through discussion with members of the observation

Table 1
Students' Actions

Category of student behavior What most students appeared to be doing	**Percent of minutes observed** Grade level cluster			
	K-1	**2-5**	**6-8**	**9-12**
1. Listening/Watching/ Taking Notes	9.9	26.2	30.1	31.7
2. Questions/Answer/ Entire Class/Verbal	17.7	20.6	17.3	18.9
3. Written Work				
a. Routine practice	19.4	16.7	32.4	23.7
b. Investigations	0.0	1.1	0.6	0.2
4. Using a Manipulative				
a. Routine practice	28.8	3.0	1.7	3.7
b. Exploration	6.3	2.4	1.6	3.5
5. Using Technology				
a. Routine practice	0.2	7.2	2.5	3.9
b. Exploration	0.0	0.0	0.0	0.0
6. Group Work				
a. Routine practice	6.8	7.5	1.1	2.3
b. Exploring	1.5	3.0	0.6	0.0
c. Reporting	1.1	0.6	1.4	0.0
7. Other	0.0	3.0	4.5	3.7
8. Undirected	8.1	8.8	6.2	8.5

team and based on their teaching experience and upon the kinds of activities called for in the NCTM *Standards* (1989, p. 10). The grade level clusters were based on the organization of school buildings in this system. We chose to report percentages due to the differences in the scheduled minutes of mathematics lessons at different grade levels - from 40 to 55 minutes - and due to the large number of total minutes reported which was approximately 5600. The percents for each category of student behavior at a grade cluster were determined by dividing the minutes recorded for that category at a grade cluster by the total number of minutes recorded for that grade cluster. We observed: 17 lessons at grades K-1 for 728 minutes, 34 lessons at 2-5 for 1404 minutes, 34 lessons at 6-8 for 1642 minutes, and 37 lessons at grades 9-12 for 1861 minutes. This was a total of 122 lessons for 5635 minutes.

Every effort was made to record entire lessons. Observations were scheduled and selected to maintain a balance between advanced, regular, and remedial classes. The choice of minute intervals was consistent with Clark and Peterson's conclusion (1986) that teachers make deliberate decisions about every two minutes during interactive teaching.

Discussion

At all grade levels, students in this school system appear to us to spend most of their time sitting at their desks engaged as individuals in listening, watching, and performing routine written practice (see categories 1,2, and 3, above). Other than in grades K-1, hands-on types of activity (categories 4 and 5) seem rather infrequent. Investigations in written work, with manipulatives, with technology (there was a computer in every classroom), or in group settings, occurred with an infrequency some might claim as akin to the approach of Haley's Comet (see categories 3b, 4b, 5b, and 6b). After grades K-1 students appear to spend but five percent of class time with manipulatives. After grades 2-5 students spent only about three percent of class time in group settings.

Procedural knowledge, in the form of practice on routine skills and factual information, seems to have gotten considerable attention (categories 3a, 4a, 5a, and 6a), garnering at least 55% in grades K-1, 34% in grades 2-5, 38% in grades 6-8, and 34% in grades 9-12. We note "at least" in that a portion of the time spent in categories 1 and 2 also went to procedural concerns. If we assume that one-third of the time spent in categories 1 and 2 was spent on how to do something then these percentages climb to 64, 50, 54, and 51. Mathematical activity (as described earlier) appears in categories 3b, 4b, 5b, 6b and 6c, and receives less attention –with percent totals for the increasing grade levels from these five categories being 9, 7, 4, and 4. If we assume, perhaps generously, that one half of the time spent in categories 1 and 2 was devoted to mathematical activity, then these percentages rise but to 23, 30, 28, and 29 across the increasing grade levels.

If one considers the balance of classroom activity as reported above as being in favor of skills over mathematical activity, critics of the NCTM *Standards* (Cheny, 1997; Kronholz, 1997; Ratnesar, 1997) would seem to have little to complain about in this school system—especially when one also considers that traditional modes of instruction (categories 1, 2, and 3) consumed about 50% of class time in grades K-1, 60% in grades 2-5, 80% in grades 6-8, and 75% of class time in grades 9-12. It might be interesting to hear the reactions of these same critics when it is noted that we were asked to examine the mathematics program in this system because students' test scores in computation and concepts on national standardized tests were considerably below those of similar and neighboring school systems. Students' test scores were also low in computation and concepts in comparison to a national sample of school systems of approximately the same size and percent of students on free or reduced lunch. In this school system, spending a large amount of class time on procedural knowledge in traditional instructional settings did not result in acceptable student performance on standardized tests.

With respect to the data on students' actions, our response to research questions 1 and 2 is that traditional modes of instruction, wherein students as a large group primarily watch, listen, take notes, and respond to questions on matters mainly dealing with mostly procedural knowledge, characterized these classrooms. We note that there did not appear to be a balance between skills and mathematical activity. The data tends to support Forgione's concern that our mathematical focus is on teaching students how to do something.

Student Processing

Another look was taken on how we judged most students to be called upon to think in these lessons. While these categories are subject to a wider interpretation among the observers, inter-rater agreement remained high (89%). In relation to research questions 1 and 2, we attempted to ascertain to what extent students were being asked to process information in categories we judged to include the four major NCTM Standards: Reasoning, Connecting Ideas, Communication, and Problem Solving (NCTM, 1989). It is the engagement of these Standards that enables mathematical activity to occur.

The grade level clusters below again represent the organization of buildings in this school system. The student behavior categories were driven by the authors' and observation teams' K-12 teaching experience and interpretation of indicators of mathematical activity discussed in the NCTM Standards.

In tabular form below we present the findings of the observations. Students' activity was tallied each minute by experienced classroom teachers, mathematics supervisors, and college level mathematics educators. To represent each of the grade level clusters one hundred and twenty-two entire lessons were observed on a random basis. The choice of minute intervals was again chosen based on Clark and Peterson's conclusion (1986) that teachers make deliberate decisions about every two minutes during interactive teaching. Percentages are reported due to the differences in the scheduled minutes of mathematics lesson at different grade levels - from 40 to 55 minutes - and due to the large number of total minutes reported which was approximately 5600.

Table 2
Students' Thinking

Category of Student Behavior What most students appeared to be called upon to process	**Percent of Minutes Observed** Grade level cluster			
	K-1	**2-5**	**6-8**	**9-12**
1. Reasoning, Connecting Ideas, Communicating, Problem Solving	26.2	39.0	20.0	25.4
2. About the steps in a Procedure (Practicing) or Recalling factual information	28.0	35.6	57.3	46.8
3. Considering a Model or Relating a Model to Symbols	31.5	6.8	4.8	8.3
4. Other (e.g., requirements, behavior)	0.0	3.7	3.9	3.4
5. Not Paying Attention	14.3	14.8	14.1	16.2

Discussion

Thinking about the steps in a procedure or recalling factual information (category 2) consumed the largest percentage of time in grades 6-8, and 9-12. In grades 6-8, thinking about the steps in a procedure, or recall of factual information, appeared to occupy students thinking nearly 60% of the time. This was nearly triple the time spent in mathematical activity i. e., thinking along lines of the major NCTM Standards (category 1). In grades 9-12 thinking about procedures or recalling facts appeared to occur nearly half of the time. This was almost double the time spent in Reasoning, Connecting Ideas, Communicating, and Problem Solving. In grades 6-8, and 9-12 not much time was observed in category 3 -- which perhaps is as close as our observation scheme comes to identifying time spent on conceptual knowledge.

The dominance of category 2 over category 1 in grades 6-8, and 9-12 hardly leads students to consider mathematics as a thoughtful, understandable, enterprise—it is robbing mathematics of much of its power and beauty. The extreme scarcity of Investigations in the first table (categories 3b, 4b, 5b, and 6b) underscores this concern.

In grades K-1 and 2-5, time spent thinking about the steps in a procedure or remembering facts (category 2) was about equal to the time spent in all four of the major NCTM Standards (category 1). Thus there is indication of a little more balance between mathematical activity and procedural knowledge at these grade levels than was seen in 6-8 and 9-12. In grades K-1, there was an additional balance. Categories 1, 2, and 3, (mathematical activity, procedural knowledge, and conceptual knowledge) each received about the same amount of time.

With respect to the research questions, our data indicate that thinking about procedural matters gets the lions share of attention over mathematical activity and conceptual issues in grades 6-8 and 9-12 in this school system. There is a better balance in thinking about procedures, concepts, and mathematical activity in grades

K-1, and nearly "equal time" spent between thinking about procedural matters and mathematical activity in grades 2-5.

Except at K-1, the scarcity of thinking about models and relating models to symbols (category 3) adds to the position that traditional mathematics teaching and learning, with its emphasis on factual information and procedural matters, and not Standards-based mathematics, makes a very large impression on students in these mathematics classrooms. We note that failure to pay attention seems rather constant and perhaps significant at all grade levels—occurring about 15% of the time.

We believe our data on what we judged students to be called upon to think about, and the size and random nature of our sample of mathematics lessons for grades 6-12 in this school system, also supports Forgione's concern—that procedural knowledge gets more attention than concepts or mathematical activity.

Student Teacher Data

The data below was gathered by one of the authors from two of four required observations of five secondary school student teachers in fall semester 1998. These student teachers had received a mathematics education undergraduate program at the University of Georgia. The mathematics component of this program required nine courses beyond the year-long Calculus sequence and included Geometry, Modern and Linear Algebra, Probability and Statistics, and computer intensive mathematical problem solving. The mathematics education components of this program included a ten-day September (school opening) participation, and curriculum and field-based methods courses. The curriculum course was taught in conjunction with the computer intensive mathematical problem-solving course. The field-based methods course was accompanied by a seminar which featured group meetings for reflection after each of ten days of small group teaching in a public high school. Ten weeks of student teaching followed these courses and was itself followed by five weeks of seminar reflecting on the student teaching experience.

Data was gathered from ten lessons (371 minutes of instruction). This was two lessons per student teacher. It is displayed below. As these were secondary teachers, only grades 9-12 are represented. For ease of comparison, the 9-12 data from experienced teachers' classrooms presented earlier (rounded to the nearest percent) is also shown.

Table 3
Comparing Students' Actions

Category of Student Behavior What most students appeared to be doing	**Percent of Minutes Observed** Grade level cluster 9-12	
	Student Teachers	**Experienced Teachers**
1. Listening/Watching/ Taking Notes	37	32
2. Questions/Answer/ Entire Class/Verbal	21	19
3. Written Work		
a. Routine practice	22	24
b. Investigations	0	0
4. Using a Manipulative		
a. Routine practice	0	4
b. Exploration	0	4
5. Using Technology		
a. Routine practice	4	4
b. Exploration	1	0
6. Group Work		
a. Routine practice	4	2
b. Exploring	2	0
c. Reporting	0	0
7. Other	6	4
8. Undirected	3	9

Discussion

There does not appear to be substantial differences between what students were observed to be doing in student teacher led secondary mathematics classrooms and that observed in experienced teachers' classrooms. Students in student teacher classrooms, like those in experienced teachers' classrooms, appear to us to spend most (at least 75% of their time in both cases) of their time sitting at their desks engaged as individuals in listening, watching, and performing routine written practice (categories 1,2, and 3). In both settings there is a scant amount of group work, exploration or investigation, and use of technology. Although the sample is small, there does not appear to be any reason to surmise that the foregoing answers to the research questions change when we record what students appeared to be doing during the student teachers' lessons.

With respect to the kinds of information we judged students to be called upon to process we observed the following:

Table 4
Comparing Students' Thinking

Category of Student Behavior What most students appeared to be called upon to process	**Percent of Minutes Observed** Grade level cluster 9-12	
	Student Teachers	**Experienced Teachers**
1. Reasoning, Connecting Ideas, Communicating, Problem Solving	15	25
2. About the steps in a Procedure (Practicing) or Recalling factual information	47	47
3. Considering a Model or Relating a Model to Symbols	25	8
4. Other—e.g., requirements, behavior	11	3
5. Not Paying Attention	2	16

Discussion

Students in the classes of experienced teachers and students in the classes of student teachers each appeared to be spending about one half of their time thinking about the steps in a procedure or recalling factual information (category 2). Mathematical activity and conceptual knowledge (categories 1 and 3) appear slightly more in student teachers' lessons -- accounting for 40% of the time in student teachers' lessons and 33% of time in experienced teachers' lessons. This is a rather small difference and we note it with a good deal of caution as the sample of student teacher lessons is small -- ten lessons across 5 student teachers. This small set of student teachers may have been influenced by their training, or by some other factors such as their dispositions or supervising teachers, to focus more on mathematical activity and conceptual knowledge than our large sample of experienced teachers. If such is the case, it is tempered when one notes that the means to engage in mathematical activity and conceptual knowledge do not include much investigation, exploration, technology, or group work. It appears that these student teachers employed telling, and asking questions of the entire class, and routine written practice, as their primary modes of promoting thought.

Keeping in mind the small size of our sample of student teachers, we tentatively answer the research questions for student teachers a little differently when recording what we judged students to be called upon to think about. While these student teachers, like experienced teachers, guided or directed students to think about procedural knowledge about one half of the time, they do appear to use slightly more of the remaining lesson time to have students engage in mathematical activity and conceptual issues albeit in traditional modes of engagement. Student teachers appeared to emphasize models and relating models to symbols more than experienced teachers. On the other hand, experienced teachers appeared to emphasize Reasoning, Connecting Ideas, Communicating, and Problem Solving more than this small sample of student teachers. These differences appear rather large and should be considered further in a study with a larger sample of student teachers.

Teacher Education Issues

In the 1990's many mathematics classrooms in the United States appear to include a great deal of attention to recall of facts and procedural matters (NCTM, 1998, p.44). This content appears to be presented to students in traditional modes of instruction. The school system we studied, and the five student teachers we observed, were no exception. Like it or not, pressure for test scores, beliefs of teachers and parents, and the appropriateness of basic skills and facts to the learning of mathematics, make it likely that our classrooms will continue to give serious attention to mathematical procedures and facts.

Implementation of the NCTM Standards for curriculum, evaluation, and teaching is likely to be stymied as long as factual information and carrying out algorithms get the lion's share of teachers' and students' time and attention. The tragedy to us is that students' performance on, and indeed appreciation of, facts and procedural matters can improve if less but more efficient attention is given to them. Teachers do not seem to know how to teach skills effectively and efficiently. They seem to believe that if skills are weak that more time will fix the problem—sadly, it won't. It may be that mathematics methods courses, and professional development activities for teachers, do not give adequate attention to efficient and effective teaching and learning of facts and procedural matters. It is not enough to say we can take time from teaching basic skills and use this time for students to explore, conjecture, reason, and communicate in problem solving activities. We must be able to show how less (but more efficient) time on basic skills can result in improved student performance in this area. Perhaps then teachers will believe they have time for higher order mathematics activities.

Many parents and teachers place a great deal of importance on basic skills and facts (Kronholtz, 1997). Constructivism may have established its place in the teaching and learning of concepts, but it has yet to demonstrate to us its appropriateness for learning procedures and facts. Being able to show connections between basic arithmetic facts and constructing personal algorithms is necessary and desirable, but has not been shown to be sufficient for students' attaining mastery of facts and traditional procedures. We believe attaining mastery of facts and procedures also requires practice and reflection—but not nearly the amount of practice time indicated by the data in this study (Hiebert, 1990). The effects of practice on the learning of mathematical procedures has been studied and discussed for over 60 years (Thorndike, 1922; Hiebert & Lefevre, 1986).

One issue then that needs to be included in teacher education programs concerns the best and most efficient modes of practice in learning basic facts and algorithms. We should not ignore this issue when it is so prevalent in classroom practice. The NCTM Standards, and related publications, need to specifically address and present our best guidance for teaching and learning of facts and procedures and not just note that procedural knowledge can be attained in the course of problem situations (NCTM, 1989, p.8). The importance of basic skills is frequently acknowledged by leaders in mathematics education. Indeed, such a claim appears in the Curriculum and Evaluation Standards (p. 7). Judging from the scarcity of examples and addenda materials included in and flowing from the NCTM Standards, however, many mathematics educators appear to give the teaching of basic facts and algorithms lip service. The 1998 NCTM Yearbook on algorithms notwithstanding, we note that the last NCTM Yearbook addressing *classroom issues*, such as the role of practice, on computation and related matters was published over 20 years ago (NCTM, 1978). No addenda or similar materials as yet focus on appropriate and efficient classroom practices for teaching computation.

Another issue related to the teaching of basic skills is attention to the "How" and the "Why" of algorithms. Should students first learn how to carry out an algorithm e.g., adding fractions or a procedure such as factoring trinomials, and then learn why the steps are mathematically correct? Or, should students learn how and why together, or even why before how? It appears to us that most mathematics programs teach how and why together. This may be a more difficult task and may frustrate student desires to initially get correct answers. Only a modest amount of research appears to address this question (Cooney, 1981).

If mathematics teachers perceive basic facts and procedures as critical, and feel unsuccessful in teaching them, then visions, exhortations, examples, and materials to foster the construction of concepts and problem solving may be viewed by teachers as material to come after mastery of "the basics" is attained by students. This may serve to restrict mathematical experiences for many students. We fear that if teacher education programs do not prepare teachers to meet their perceived need for effective teaching of basic facts and procedures, then these programs run risk of being seen as dealing in matters that are nice but for which there is little time. This is regrettable as concept learning, problem solving, and computation have long been viewed as complimentary activities (Hamrick & McKillip, 1978). Teacher education programs and activities need to reflect all three working together in model lessons and in assessment practices.

The truth of the matter is that, like a good diet, a sound mathematics program needs to contain a balance—a balance of conceptual and procedural knowledge, and the problem solving and mathematical activity that uses this knowledge (Brownell, 1956/1987). Would the same not also hold true for a sound teacher education program?

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Conferences…

NCTM's 78th Annual Meeting; April 12-15, 2000 in Chicago, Illinois
http://www.nctm.org/meetings/2000/Chicago/news/invitation.html

BRIDGES: Mathematical Connections in Art, Music, and Science; July 28 - 30, 2000 at Southwestern College, Winfield, Kansas; http://www.sckans.edu/~bridges/

ICME-9, Ninth International Congress on Mathematics Education; July 31 to August 6, 2000 in Tokyo/Makuhari, Japan; http://www.ma.kagu.sut.ac.jp/~icme9/

History in Mathematics Education: Challenges for a new millennium; August 9-14 in Taipei, Taiwan.
http://www.math.ntnu.edu.tw

PME-NA XXII, Twenty-second Annual Meeting of the International Group for the Psychology of Mathematics Education; October 7-10, 2000 in Tucson, Arizona; http://www.west.asu.edu/cmw/pme/

TIME 2000-An International Conference on Technology In Mathematics Education; December 11-14, 2000 in Auckland, New Zealand; http://www.math.auckland.ac.nz/Conferences/TIME2000/firstann.html