Improving Access to Science and Math Education in Western Pennsylvania

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Seven out of every 10 American jobs are expected to be related to technologies using advanced computers and electronics, requiring workers with strong math and science skills. However, school systems in several regions in the US that have suffered economic and demographic declines are having problems maintaining and improving math and science education. We conducted a study and engendered cooperation between school districts to improve student access to math and science courses in one such region. We first examined the math and science curricula, predicted enrollment rates, forecasted teacher availability, and analyzed access characteristics for a set of school districts in Western Pennsylvania known as the Mon Valley Education Consortium. We then proposed strategies for cooperation between the school districts that included moving students to multiple centers for advanced math and science courses, moving teachers between schools, and using an area vo-tech school as a math and science center. As a result of the study a pilot project was implemented signaling the beginning of regional cooperation in the area.

For those parts of the US that have suffered economic dislocation, the problem of improving their educational systems is compounded by stagnant or

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declining tax bases and, in some cases, enrollment decline as families move out of these regions to seek better economic opportunities. Nonetheless, the school systems continue to educate large numbers of children and need to address the educational needs of tomorrow's workplace. In this study, we focused on one such distressed region, the Mon Valley in southwestern Pennsylvania. The most notable trend in the regional economy is the ongoing decline in manufacturing employment. From 1979 to 1983, approximately 50,000 jobs were lost in primary metals. In 1980, 37 percent of all local manufacturing jobs were in the steel-related industries. By 1983, that percentage had declined to 29 percent, and it may slip further by the year 2000. In the past, high school graduates in the Mon Valley pursued careers in heavy manufacturing and were able to earn more than college graduates. In 1983, the steel industry was paying nearly $23 an hour, enough to support a family. The decline in heavy-metals industries in the early 1980s decreased job opportunities for young workers and left thousands of low-skilled workers dislocated. By the late 1980s, the economic situation had changed, and high school graduates without a college education faced an uncertain future when only a decade ago they would have been able to secure a high-paying position in the steel mills.

Many people left the Mon Valley seeking employment in other regions. The population declined steadily and with it, student enrollment. From 1970 to 1982, Pennsylvania experienced a 24.5 percent decline in enrollment while the nation lost only 13.6 percent. Furthermore, from 1980 to 1985, while the national rate of enrollment tapered off to 3.6 percent, school districts in southwestern Pennsylvania suffered an 11.8 percent annual decline in enrollment. By the 1987–1988 school year, national enrollments were showing steady growth in the elementary grades while elementary enrollments in Pennsylvania were just beginning to grow. As school enrollments declined, districts losing large numbers of students needed to cooperate to provide high-school students in the region with educational opportunities equal to those in districts with stable enrollments. This was especially true for math, science, and computer science because of their increased importance for jobs of the future.

Approximately 50,000 jobs were lost in primary metals.

Educators who previously did not need to emphasize increased math and science skills for their students were now compelled to reexamine their curricula. The Mon Valley Education Consortium was established to create a new sense of community among the communities devastated by the region's economic decline. The Mon Valley Education Consortium is an organization of 20 school districts centered around the Monongahela River Valley. These school districts are dispersed among Allegheny, Fayette, Washington, and Westmoreland counties. Based on a request from the Mon Valley Education Consortium and support from the Howard Heinz Foundation and the Ben Franklin Partnership, we conducted a study with the objective of improving student access to advanced math and science courses.

Key Findings of Study

Our research efforts in the two-year period 1989–1991 had two distinct components. The first part included a study based on a survey of the 20 schools in the Mon Valley Education Consortium and 32 other school districts in Allegheny County with a view to comparing science and math opportunities among schools of different size and fiscal capacity in terms of course offerings, student enrollment, teacher qualifications and availability, and equipment availability.

Using the data collected from our survey, national student enrollment rates from the National Transcript Study, and high-school enrollment projections provided by the Pennsylvania Department of Education, we (1) compared student enrollment rates in math and science courses in the Mon Valley Consortium to national enrollment rates, (2) measured the math and science curriculum in the Mon Valley and explored factors that may affect a school's ability to offer math and science courses, (3) predicted enrollment rates in math and science based on the aggregate curriculum offerings and estimated enrollment patterns, and (4) forecasted the availability of teachers qualified to teach advanced-placement science courses over the next decade. Some of our major findings follow:

—Student enrollment rates in advanced-placement (AP) science courses in general tended to be weak compared with national and regional levels. Also, math and science curriculum enrollment rates were consistently below regional or national levels.

—One of the major factors influencing the low enrollment rates for elective science courses was that they were often not as frequently available in consortium schools as elsewhere. However, a small number of students demanded these courses within each school district.

—The size of a high school appears to have a strong impact on its curriculum. Because larger schools have greater resources that make specialized and advanced courses more feasible, the larger a school's student enrollment, the more advanced science courses it offered.

—In the next few years, enrollments in the Mon Valley were expected to continue to decline, which would mean that the few schools that currently offered advanced-science electives would face even more difficulties.

—We should expect a teacher shortage in the future if present trends continued because teacher inventory was expected to fall at a much faster rate than student enrollment. The supply of teachers with 30 years of experience was expected to drop by 60 percent over the next 12 years. The supply of teachers with 27 years of experience was expected to decline by 21 percent. By contrast, student enrollment was projected to fall by only 12.3 percent.

Access Characteristics of the Mon Valley Schools

The consortium school districts varied considerably in high-school enrollment and in geography. High-school enrollment varied from a high of 2,355 for Woodland Hills to a low of 303 for Duquesne. School districts ranged in size from 67 square miles (Yough) to 2.1 square miles (Duquesne). Ranking districts by area, we found that some of the large school districts had some of the lowest enrollments, whereas few small districts had high enrollments compared to other schools in the consortium. Since the consortium schools were dispersed over a large area, it was essential to understand transportation issues. Any program aimed at increasing students' access to math and science education would involve either bringing students to schools that offered advanced courses or sharing teachers between schools. Transportation cost could be one of the largest components of such a program. We collected information on distance and travel times between schools, transportation costs in each school district, and whether each district owned and operated its own buses or contracted with privately owned bus companies. The study team actually measured travel times and distances between all pairs of schools, after consultation with school district transportation coordinators and bus company officials. We checked these estimates for consistency with interzonal estimates provided by the Southwest Pennsylvania Regional Development Corporation and by bus-company officials. Travel times between schools varied from a high of 67 minutes (Woodland Hills to California) to a low of five minutes (West Mifflin to Duquesne).

We employed two broad approaches based on cooperation among the consortium school districts in constructing alternatives that would raise enrollment rates in advanced-placement courses in the consortium school districts to current national levels: (1) moving students to one or more central centers for advanced math and science courses, and (2) moving teachers to students.

Establishing Multiple Centers

The first approach entailed choosing center locations that would keep the maximum travel time from any school to the nearest center reasonable. We used a set-covering model [Larson and Odoni 1981] to determine the number and locations of centers given a specified time constraint. Set-covering solutions minimize the number of center locations needed to ensure that every school is served by at least one center. As time constraints change, so do the number of centers required to "cover" all the schools (Figure 1). With a maximum travel time of 10 minutes, 14 centers were needed. At 14 minutes, the number of centers required dropped to eight. Between 26 minutes and 41 minutes, the number of centers remained constant at two. A single center would suffice for maximum travel times of 42 minutes or more. When we obtained multiple optimal solutions, we chose the one that yielded the minimum average travel time per student.

Moving teachers from school to school raised the question, Who is the employer?

We discussed our findings with several district superintendents and agreed that travel times of 15 and 20 minutes were reasonable time objectives for transporting students throughout the day. Consequently, we built scenarios around maximum travel times of 15 minutes, which

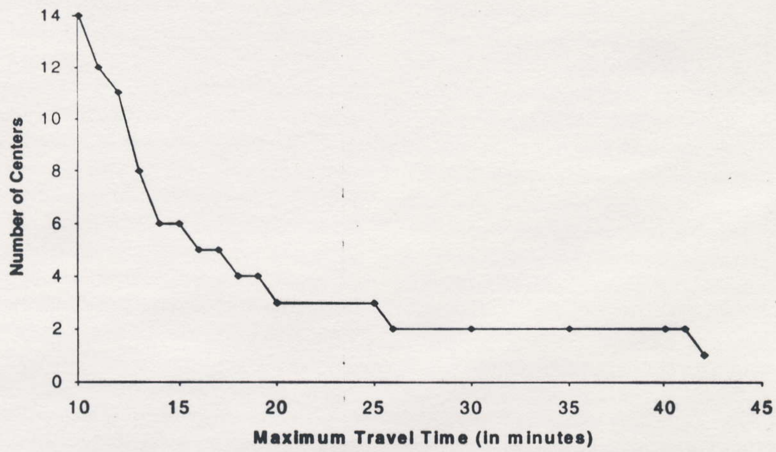


Figure 1: The number of math-and-science centers decreases as the maximum travel time increases. The shape of the trade-off curve is exponential with the sharpest drop between 10 and 20 minutes. Each point on the curve represents the solution to a set-covering problem.

yielded six centers, and 20 minutes, which yielded three centers. For each of these scenarios, the solution of the relevant set-covering problem yielded the center locations and the schools served by each center.

Next we estimated demand for advanced-placement courses in biology, chemistry, and physics at each of these centers. First, we calculated demands for AP courses in each school district by multiplying the projected high-school enrollment level by the current average enrollment rate in AP courses in the schools that currently offered them. We then used school-level demand projections to estimate demand at each math-and-science center under each scenario. Classes were to be held during the first and last periods of the day. This arrangement required students to travel before or after their regularly scheduled school day but allowed them to maintain a daily schedule at their home schools. For example, a student taking a morning class at the math-and-science center would travel from her home to the local high school and then take the bus to the math-and-science center. After attending the class at the center, she would take the bus back to the local high school and continue with her regular schedule of classes. Once we had determined total class demand and class time, we estimated the number of sections based on an optimum class size of 20 to 30 students. If a particular course were to be offered once in the morning and again in the afternoon, we assumed that the same teacher would teach both sections. For example, at the McKeesport center, a total of 115 students would take advanced-placement biology. Fifty-six of the students would attend the morning class, while 59 would come in the afternoon. Six sections of AP biology would be needed to maintain an optimum class size of 20. Since one teacher could teach both a morning and an afternoon class, only three teachers would be required. Fourteen teachers were required for the three-center alternative (seven teachers at McKeesport, three teachers at Bethlehem Center, and four teachers at Charleroi) (Figure 2).

Moving Teachers

Under the second scenario, teachers would move from school to school. The traveling teacher would teach one period at a school, travel to the next school during the following period, teach at that school the subsequent period, and so on. Determining the number of teachers needed to serve the school districts became known as the traveling-teacher problem. Examination of the travel-time matrix revealed that the longest travel time between any two neighboring schools was 14 minutes, which was well under 50 minutes—the length of a typical period. We then used a minimum spanning tree based on distances between schools to generate traveling-teacher routes for consortium schools (Figure 3). This strategy would require 17 teachers (six biology, six chemistry, and five physics).

Cost Components and Implications of Proposed Scenarios

All proposed alternatives had three major cost components: teacher cost, equipment and material cost, and transportation cost. From our teacher-retirement projections, we surmised that new teachers with only a few years' experience would probably be hired to teach at the centers. We used two cost estimates for teacher costs. In one case (reported here), we assumed that all teachers would be newly hired and estimated teacher costs using the median salary of a teacher with one year of experience. In the other case, we used the median salary for math and science teachers in consortium schools. We estimated equipment and material costs by developing minimum equipment standards for the three types of laboratories based on interviews with instructors in biology, chemistry, and physics.

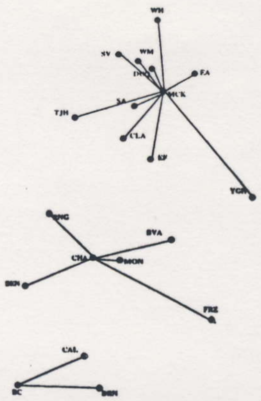
Transportation costs were more difficult to estimate. Average travel time decreased from 11.35 minutes in the three-center scenario (which had a maximum travel time of 20 minutes) to 7.22 minutes in the six-center scenario (which had a maximum travel time of 15 minutes). Clearly, if transportation costs were proportional to average travel time (or total travel time), the six-center scenario would have lower transportation costs than the three-center scenario. However, a number of factors influenced overall transportation costs: the number of students, distances, time of day, availability of buses, and whether a school district owned and operated its own buses or contracted with privately owned bus companies. Cost savings that might result from a district owning its own buses versus contracting with a private bus company depended on the personnel and maintenance costs associated with owning the buses. At the time of the study, six schools owned and operated their buses, 12 schools contracted out all bus service, and two schools used both their own buses and independent contrac-

Center	Participating Schools	AP Biology	AP Chemistry	AP Physics	Total Estimated Students
McKeesport (MCK)	McKeesport (MCK)	25	9	17	51
	Clairton (CLA)	5	2	3	10
	Duquesne (DUQ)	4	1	3	8
	East Allegheny (EA)	11	0	7	18
	Elizabeth Forward (EF)	18	0	12	30
	South Allegheny (SA)	9	3	6	18
	Steel Valley (SV)	13	4	8	25
	West Jefferson (TJH)	0	0	10	10
	West Mifflin (WM)	16	6	0	22
	Woodland Hills (WH)	0	0	0	0
	Yough (YGH)	14	5	0	19
	Total	115	30	66	211
Bethlehem Center (BC)	Bethlehem Center (BC)	7	2	4	13
	Brownsville (BRN)	14	5	10	29
	California (CAL)	6	2	4	12
	Total	27	10	18	54
Charleroi (CHA)	Charleroi (CHA)	11	4	7	22
	Belle Vernon (BVA)	17	6	0	23
	Bentworth (BEN)	7	2	5	14
	Frazier (FRZ)	8	3	5	16
	Monessen (MON)	5	2	3	10
	Ringgold (RNG)	22	8	0	30
	Total	70	25	20	115

Figure 2: The three-center scenario was developed from the solution of a set-covering problem with a maximum travel time of 20 minutes. The table displays the corresponding enrollment projections.

tors to provide bus service. We developed three estimates of transportation costs. The first estimate assumed that an independent contractor would provide all bus service. We based the costs on prices provided by independent contractors. The second estimate assumed that only schools that currently contracted their bus service would continue to do so, while schools that owned their buses would use them to transport students. We developed the third estimate as an upper bound on transportation costs and used the reimbursement rate schools pay parents who provide individual transportation for their children.

We compared the per-student cost of the alternatives (Table 1). We assumed that teachers were scheduled for an eight-period day that includes six teaching periods, a preparation period, and a lunch period, and that the school at which the



The figure depicts the relative location (north is toward the top of the page) of the math-and-science centers and participating schools.

center would be located would use this teacher to teach other courses for students of the center school. The center required teachers for only one-third of the day (two classes). However, it was unlikely that a teacher would be available and willing to teach only two periods a day, especially the first and last periods of the day. For purposes of the project, we assumed the full cost of the teacher would be incurred regardless of how many periods of the day were actually devoted to teaching AP math and science courses. Hence, we developed two estimates of teacher cost: one based on the entire salary (Table 1, column 3) and the other based on only that component of teacher salary associated with AP math and science courses (Table 1, column 4). For example, for a teacher teaching two sections of an advanced math or science course a day, two-sixth of the teacher's salary would be allocated to the costs of the math-and-science center. If government subsidies were available to offset portions of the teacher costs not used for teaching science, the cost estimate based on just the AP math and science portion of teacher costs would be most appropriate for evaluating alternatives (Table 1, column 4). However, in our cost comparisons we used total costs (Table 1, column 3). The moving-teachers scenario was the least costly of the three alternatives. The moving-students strategy was less sensitive to the level of teacher salaries since teacher costs make up only 58 percent of the total cost of the three-center option and 56 percent of the six-center option as opposed to 92 percent in the moving-teachers scenario. Real trade-offs existed between the two strategies. While the advantages of moving teachers included smaller class sizes, lower transportation costs, and avoiding student traveling time, the disadvantages included the high cost of establishing proper labs at all high schools and wasted laboratory space at schools with declining enrollment. Laboratory facilities and equipment would have to be maintained at all schools. In the long run, this might be more expensive than sharing facilities and equipment. With declining enrollments, facilities set up today may be empty tomorrow. Shared facilities would not be prone to being vacated.

The almost $200,000 difference in costs between the three-center and six-center alternatives was attributable to the need for six more teachers and the additional transportation costs. If the per-student cost differential of $547.04 were translated into a per-hour amount, the cost per student of providing a lower maximum travel time

Teacher	Period 1	2	3	4	5	6	7	8
Biology								
A		BRN		CAL			BC	
B		FRZ		BVA		BEN	MON	
C		RNG	RNG					CHA
D		EF		CLA			SA	
E		SV		WM			DUQ	
F	YGH		EA			MCK	MCK	

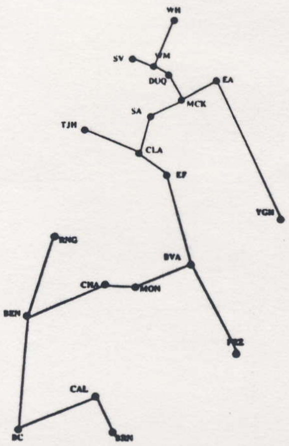
Teacher	Period 1	2	3	4	5	6	7	8
Chemistry								
A	BC		CAL			BRN		
B	CHA			RNG			BEN	
C			MON			BVA		FRZ
D		CLA		SA				
E		YGH		MCK				
F	SV		WM			DUQ		

Teacher	Period 1	2	3	4	5	6	7	8
Physics								
A			BC			CAL		BRN
B			BEN			CHA		MON
C	FRZ			EF		CLA		
D	EA		MCK			SA		
E		TJH		DUQ			SV	

Figure 3: The table displays teacher schedules under the traveling-teacher scenario where a teacher alternates between teaching at a school in one period and traveling to the next school in the subsequent period.

(of 15 minutes versus 20 minutes) would have been four times the prevailing minimum wage. This cost associated with the six-center scenario made it an unacceptable alternative.

The per-student cost of establishing three centers was $211.66 more expensive than moving teachers. The three-center alternative could be less costly than moving teachers if (1) host schools picked up a large proportion of the noncenter component of teacher costs; (2) subsidies were available from county, state, and federal authorities; (3) large numbers of students



The schedules were developed from a minimum spanning tree based on distances shown in the figure.

participated; and (4) the salary levels of the teachers employed were fairly low.

The per-student cost estimates for moving teachers and for the three-center alternative compared favorably with prevailing per-student per-class costs in consortium schools, which ranged from a maximum of $904 to a minimum of $504, with a consortium average of $670. The additional cost for the math and science courses was not seen as prohibitively high since the schools should have been willing to spend more to offer these advanced courses. Because the costs of developing three centers and moving teachers were similar, we recommended both alternatives as feasible options for providing advanced math and science education.

Reaction to Proposals

We presented our proposals to local educators. Their major concern about the multiple-center proposal was the large transportation-cost component. Given their tight financial situation, the school districts were unwilling to spend money on transportation costs. Also, the prospects of getting further state assistance were poor. The organizational issues of who would pay for the teachers and to whom they would report appeared to be quite important. We examined several alternatives. The traveling teacher (1) could be on leave from a particular home district or (2) could belong to a pool of teachers hired by the consortium or (3) could work part time in the visitor school and continue teaching in the home school. This strategy evoked tremendous interest among educators, teachers, and representatives of the local teachers' union, the Pennsylvania State Education Association (PSEA). In discussions with various groups, we learned that alternative 2 might not be acceptable because it could be seen as a move to avoid hiring new teachers or recalling laid-off teachers. It was also seen as a move to bring in a nonunion teaching core. Alternative 1 did not appear to be the best alternative either. Major concerns with this approach were that a district might not want to give up a teacher for an extended period because such a leave of absence would cause a gap in the teaching schedule at the home school and might also result in more work for the remaining teachers. Other issues the unions raised concerned the schools forestalling further hiring and questions about the seniority of the traveling teach-

The prospects of implementing the traveling-teacher scenario were dim.

Scenario	Number of Teachers	Per-Student Cost 1	Per-Student Cost 2
Three centers	14	$1,127.80 ($428,570)	$620.38 ($235,750)
Six centers	20	$1,674.84 ($631,440)	$884.47 ($336,100)
Moving teachers	17	$916.14 ($348,140)	$916.14 ($348,140)

Table 1: A comparison of the per-student cost of the three scenarios (total cost of each scenario in parenthesis) shows that the moving-teacher scenario was the least expensive when total teacher costs were considered (column titled Per-Student Cost 1). When only center-related teacher costs were considered (column titled Per-Student Cost 2), the three-center scenario was the least expensive. All scenarios had three cost components: teacher cost, equipment and material cost, and transportation cost. In calculating transportation costs, we assumed that schools that contracted their bus service would continue to do so, while schools that owned their buses would use them to transport students.

ers (alternative 3). Further, the collective bargaining situation was complicated by dual union representations for teachers in some districts: some were represented by the PSEA, others by the American Federation of Teachers (AFT). Meetings and telephone conversations with representatives from the PSEA and the AFT confirmed that moving teachers from school to school raised the fundamental question, Who is the employer? The answer to this question would determine who paid the teacher's salary and what that salary would be. In addition, who supervised the travelling teachers was an important issue.

After a series of presentations and discussions with school-district authorities, we concluded that the prospects of implementing the traveling-teacher scenario were dim. A major reason for our pessimism was that no historical precedent of such regional cooperation among school districts existed in the area. Moreover, such collective efforts had to address many complex issues, such as incremental costs, curriculum and scheduling, legal issues, collective-bargaining and transportation issues, and political implications. Consequently, we ended the year by encouraging cooperation between schools even if only between very few schools. Toward this end, we proposed the idea of "buddy" schools based on the solution of the minimum-cost (travel time) weighted matching problem [Larson and Odoni 1981].

> The lawsuit will result in changes in the funding and taxation system.

In the second year of the research, we focused on a set of schools in a region that had a more coherent institutional and geographic structure, 10 school districts that voluntarily supported the Steel Center Vocational-Technical School. Seven of the 10 schools were also members of the Mon Valley Education Consortium. We examined the feasibility of using a vo-tech school as a math-and-science center and went on to develop a pilot project that could be implemented.

The Vo-Tech Scenario

An area vocational-technical school commonly utilized by and centrally located to a large group of school districts offered advantages in terms of overall cost and students' travel time to the facility. Area vo-techs were promising candidates as locations for math-and-science centers for three reasons: (1) existing transportation networks routinely moved students between high schools and vo-tech schools; (2) vo-tech schools had existing financial relationships with participating school districts; and (3) vo-tech schools had space available for classrooms and laboratories.

The established transportation network linked the 10 high schools and the vo-tech, and the buses were largely unoccupied. The multiple-center scenario, in which schools were grouped in several feeder networks, would have required establishing new and costly bus routes. The schools using the vo-tech school were already linked by institutional arrangements and had worked with the vo-tech for many years. The per-student costs for all participating school districts in this scheme ranged from $360 to $600 for 1990–1991, and from $460 to $740 for 1995–1996. These costs included teacher costs and costs for reconstructing classrooms. Even without full amortization of capital costs, these per-pupil costs seem affordable for the participating districts.

Steel Valley Pilot Project

As the study progressed, we realized that it would take time and a lot of negotiating to work out the details of implementing the vo-tech proposal. We developed a pilot project in the interim before trying to mobilize collective efforts at a regional level. The Steel Valley pilot scenario involved three schools. Under this scenario, students from Clairton and Duquesne would go to Steel Valley High School for specific science courses. There was demand for AP science courses at all three schools, and the administrators of the host school wanted to undertake this project.

This scenario seemed quite workable. Because Steel Valley was already offering second-year courses in both chemistry and biology, it looked as if it would be easy to get Steel Valley to switch to an AP curriculum. Clairton and Duquesne did not offer such second-year science courses, and they are close to Steel Valley: Clairton is 19 minutes from Steel Valley, and Duquesne is 11 minutes from Steel Valley. Steel Valley had lab facilities, available teachers, and an interest in being the host school. Steel Valley had no new costs and actually benefited from having other participating schools contribute to its teacher costs. Students would be transported between schools by public transportation or by parents, with the school district reimbursing them for mileage.

Conclusions and Epilogue

In mid-1990, school directors of the Steel Valley school district approved an AP chemistry course to be run with the participation of students from the Duquesne school district. This signaled the beginning of regional cooperation in secondary education in the area [*Pittsburgh Post-Gazette* 1990].

While our research led to this pilot implementation of a scheme to improve student access to advanced science courses, the progress achieved was not sustained for a number of reasons, reasons that illustrate the difficulties of improving public education in poor areas. First, because the pilot was not financed by the districts themselves, they had no sense of ownership or motivation to maintain the innovation. When a private foundation was unwilling to continue providing tuition support after the 1990–1991 school year, the districts dropped the advanced-science course. Second, lack of management continuity in both districts exacerbated these problems. Within two years of the pilot, the superintendents in both districts quit their districts for better jobs elsewhere. Whatever momentum and leadership had been achieved quickly dissipated as both districts were forced to operate with acting superintendents. In one case, the departure reflected a sharp disagreement between the school-district board and the superintendent about whether the district could afford an ambitious building program. In the other case, the superintendent was attracted to a nearby rich and growing district that promised greater support for curricular innovation. Thus, in a fundamental sense, enhancing local-education offerings became a victim of the very dire economic circumstances that led to the study and pilot.

The saga took a legal turn in January 1991, when both districts, along with a number of the Mon Valley districts, joined over 100 other districts in an equity lawsuit against the Commonwealth of Pennsylvania (*Pennsylvania Association for Rural and Small Schools (PARSS) vs Casey*). PARSS argued that the state had failed to provide the same educational opportunities to its students as it did to students in wealthier areas of the state. As of June 1998, 216 districts had joined the suit. It is expected that the lawsuit will result in changes in the funding and taxation system and a change in the way education is delivered. We think that the results of the study will help legislators and educators to design funding and education schemes that encourage regional cooperation in secondary education. Futhermore, the models of cooperation developed in the study will help school districts design access programs consistent with their geographies, budgets, teacher availabilities, and enrollment projections.

Acknowledgments

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