Abstract

This paper presents successes, failures, and lessons learned from implementing a fully integrated mathematics, science, and engineering curriculum at the freshman and sophomore level. In the academic year 2000-2001 the program is in its second year of full implementation. The pilot program was begun in the fall of 1997 so that the first integrated curriculum students will graduate in the spring of 2001. Improvements in student performance and increased retention have been realized as a result of this program.

The following topics will be addressed.

- Approaches to increase administrative support and faculty participation
- Transition from traditional curricula to integrated curricula
- Funding needs for the transition
- Assessment techniques to measure impact of curriculum reform
- Methods to enhance integration between courses
- Impact on curriculum improvement at the junior/senior level

Assessment data will be presented to quantify the impact of the new curriculum. We also present mistakes that were made and "mid-course" corrections that were used to get the program refocused when necessary.

I. Introduction

Louisiana Tech University is a state university in north Louisiana with an engineering college of about 1,600 students and about 110 faculty. About 5% of the in-coming engineering students are ready for calculus, 50% are ready for pre-calculus and 45% start below pre-calculus in College Algebra. Learning from recent developments in engineering coalitions such as the Foundation Coalition\textsuperscript{1,2}, Louisiana Tech has implemented an integrated curriculum for the first two years of study in engineering (cf. Tables 1 and 2).
The main sequences in this integrated curriculum are a six course mathematics sequence and a six course engineering sequence. (Louisiana Tech is on a quarter calendar.) Every quarter of the first two years, a prospective engineering student will enroll in one mathematics class and one engineering class, which are co-requisites for each other. Students who complete the integrated curriculum have completed their mathematics requirements for most programs. They have been exposed to the whole Calculus sequence, Differential Equations and some basic Statistics\textsuperscript{4}. These students also have been exposed to engineering from day one of their studies. They have a solid background in design, data analysis, report writing, teamwork, the appropriate use of software packages (EXCEL, MathCAD) and problem solving. They also have been exposed to fundamental engineering principles in the settings of statics, circuits and thermodynamics.

Salient features of the integrated curriculum are the reliance on active/cooperative learning and the emphasis of connections across disciplinary boundaries. A formal reflection of the emphasis on cross-disciplinary work is the fact that the co-requisite engineering and mathematics classes are considered a “block”. Students that are in the same section of the mathematics class are also in the same section of the co-requisite engineering class.

All preliminary indicators available to us indicate that the integrated curriculum

- Makes students progress towards graduation more rapidly than the traditional curriculum,
- Retains more students,
- Prepares students better for junior and senior level classes as well as professional life,
- Enjoys strong and still increasing faculty support,
- Fits ABET accreditation criteria better than the traditional curriculum.

The integrated engineering curriculum started as a pilot program with 39 students in the Fall quarter of 1997. In the Fall quarter 1998 the curriculum ran with a second pilot group of 135 students. Full implementation started in Fall 1999 with requiring all (approximately 240 pre-calculus ready) incoming engineering students to enter the integrated engineering curriculum. Preliminary discussions are now held how to design an integrated science curriculum that mirrors the integrated engineering curriculum. This curriculum is intended to serve the science majors in our College of Engineering and Science and the secondary education majors served by the college.

How can an institution successfully make such rapid progress towards a total change in the students’ first two years of college? After all, the first two years are half their college experience. This question is the central theme of this paper. We will highlight the barriers that need to be overcome, how they were overcome, as well as mistakes that were made and corrected as development progressed.

II. Approaches to increase administrative support and faculty participation.

The key ingredient to success overall is good communication between faculty, between administrators and between faculty and administrators. People in different programs or different positions within a college will have different, seemingly conflicting goals. Consider for example the issue of retention of students. This is a major concern for department heads and deans, while
faculty sometimes suspects discussions on retention to be an attempt to erode standards. Also note that retention can mean “retain students within my engineering program”, “retain students within the college of engineering”, “retain students at this university” or “assure students complete an academic degree (not necessarily at this school)”. Given that funding decisions can depend on the number of students a certain program/college teaches or leads to graduation, this topic is volatile to say the least.

To make integration a reality it is necessary to understand the motivations and challenges of other academic programs as well as those of the academic leadership. Open lines of communication are a strong step towards this goal. We shall now describe critical steps in the design and pilot phase 1997-99 that allowed us to maintain and increase support on all levels. The description for the expansion phase 1999-today can be found in the section on transition to integrated curricula.

IIa. Design phase.

Systemic change can neither be mandated by administration, nor can it come about solely on the initiative of single, isolated individuals. The former will lack the needed broad support in the faculty, the latter will remain isolated with little impact beyond their own classrooms. Yet every institution has a number of faculty that are interested and actively involved in improving classroom instruction. These are the individuals that were targeted at Louisiana Tech University in early 1997. A core group of nine individuals was formed and charged with the development of the integrated curriculum. This core group consisted of one associate dean, one academic director, one program chair, five faculty that knew the university and one new hire (summer 1997). All engineering programs and mathematics, physics and chemistry were represented in the core group. This group set its own goals for the outcomes of the curriculum and designed the course sequence as well as the courses. The overall goals for the curriculum were set as

- The introduction of key theoretical concepts “in context.”
- The development of better teaming and problem-solving skills in students.
- The development of the necessary technological skills in students.
- The improvement of students’ communication skills.
- The elimination of unnecessary duplication in the curriculum.
- Increased retention rates for students in the integrated curriculum and speedy progress of these students towards graduation with particular attention to be given to women and underrepresented minorities.

Note that this list of goals is entirely faculty generated and that a goal of administrative interest such as increased retention is actually a natural consequence of the achievement of the earlier goals. The goals were set around the time the ABET 2000 accreditation criteria were finalized. Upon first seeing the ABET 2000 criteria, the parallel development appeared natural (though still striking) and showed the core faculty that they were on the right track. Indeed, much of the vaunted “a-k” is incorporated in our goals. These goals were not kept internal to the core faculty. The goals were mentioned and discussed in meetings throughout the college. Suggestions from outside the core group were discussed and incorporated as appropriate. The presence of administrators in the core group automatically facilitated communication with administration. At
the same time it must be pointed out that all members of the core group functioned as *faculty with equal rights and responsibilities*, independent of their place in any (perceived or actual) hierarchy outside the core group. Heated discussions and disagreements were settled within the group or at least left within the group. There was no jockeying for support from the outside for or against a particular position.

From the start the idea was to design a curriculum that is good for the college as a whole, not to set a competition for getting the most for a particular program out of the design. This meant for some programs that courses had to be taught earlier or later than had been done previously. Yet all these decisions were supported by sound reasons. In terms of content alignment, mathematics often was the driving factor. As a simple example consider that Physics I and Physics II are not taught back to back in the integrated curriculum. The implicit assumption always was that Physics II would immediately follow Physics I. Yet this would either mean teaching Physics I in the sophomore year or teaching Physics II before any multivariable calculus has been taught in mathematics. The solution was to follow Physics I (Mechanics) with a Statics and Strengths of Materials class, which builds upon Physics I. This allowed Physics II (Electricity and Magnetism) to move parallel to Vector Calculus and Circuits. Programs also delayed teaching core classes within their areas in favor of integrated overall core classes as long as this was appropriate. This is consistent with the idea that the overall focus was to produce quality engineers of every kind. The structure allows students to transfer between programs nearly without penalty until the end of the sophomore year. The idea of retention had changed from “retention in my program” to “retention within engineering”. Later on, seeing some students transfer successfully to the sciences changed the idea to “retention in engineering and science”. This is one reason for the current discussions on an integrated science curriculum.

IIb. Pilot Phase.

A design is only as good as it ultimately works in tests and in practice. The most efficient choice for the pilot phase (starting Fall 1997) was that the faculty who designed the integrated courses would also teach them for the first time. In this fashion, miscommunications between designer and practitioner were circumvented and the faculty had direct feedback on their designs. Successes as well as challenges were reported to each other as well as to outside faculty to solicit input. Faculty within the core group also were free to voice concerns about problems occurring in other classes.

Seeing the effects of a concurrent class in one’s own students is a learning experience like no other. Someone’s routine tasks that students should perform can appear as highly challenging, even unreasonable, to other faculty. The specific challenge that we faced was that too much content was put in certain places, creating “bottlenecks” in the curriculum. We believe that such bottlenecks exist in any curriculum. Yet the bottlenecks are much easier to observe in an integrated structure than in a nonintegrated curriculum. In a nonintegrated situation, students often avoid bottlenecks by not taking certain classes concurrently. Unfortunately, this leads to students falling behind in sequences of courses that are prerequisites for each other. This is not a good option in any curriculum and it is deadly to any attempts of integration between courses. To illustrate bottlenecks that were observed and removed consider the following two examples.

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First, the integration of two Pre-calculus courses and Calculus I delayed some material that used to be Calculus I (applications of differentiation) into the third mathematics course. The third mathematics course is linked with Physics I, so it is natural, even imperative, that integration and some differential equations are covered. These demands created a course that contained the most challenging parts of Calculus I and Calculus II plus an introduction to differential equations in one 10 week quarter. Students in the pilot programs bent (but did not break) under the load and voiced their concerns. The faculty member who designed and taught the course was requested to meet with some of the core team members to discuss the situation. All these members also happened to hold administrative appointments (associate dean, academic directors), making the situation appear volatile or even potentially punitive. Yet the situation was resolved without any damage to faculty, curriculum or students. Once all concerns were voiced it became clear that the faculty member was demanding and that the course had too much content. The faculty member remained demanding. Indeed the instructional style was explained and not questioned subsequently. For the courses it was agreed to redesign the sequence to better spread the content. After this meeting, the situation was explained to the students who accepted the challenges ahead. Most Calculus I topics have since been moved to the first and second mathematics courses through re-design of these parts of the sequence.

As a second example, there was a similar situation in the first quarter of the sophomore year. The Statics and Strengths of Materials class is the first core engineering class that focuses on a specific area. As one of the intents is to strengthen students’ lab skills, the course initially was heavy in labs and lab reports. The sheer workload proved challenging for many students. Students were observed to desperately try to stay awake in the mathematics class, having spent the previous night writing reports and keeping up with other classes. The overall effect was that students did not learn as well as they could because of exhaustion. Interestingly enough the demanding faculty member from the previous paragraph was one of the advocates of lightening the overall load in the first sophomore quarter. Discussions that were held were similar to the discussions about the third mathematics course. Ultimately the number of lab reports (not the number of labs) was reduced and also some content from the fourth mathematics course was shifted to the fifth. Again, a bottleneck was removed through conscious re-design that puts the overall goal and careful observations over hasty searches for the “quick fix”. Feedback from other classes as well as the willingness to analyze the overall structure (not just the spot where the challenge occurred) were important contributors to success.

Experiences as the above strengthened the collegial spirit within the core faculty and also allowed for positive feedback to other faculty and students once problems were overcome. Students in the pilot group were overworked at times. Yet their voices were heard and students were aware of this fact. This simple-sounding measure helped maintain a good atmosphere in the pilot classrooms. Reports of the challenges and solutions to faculty outside the core group strengthened the reputation of the integrated curriculum. It helped avoid the impression that in the integrated curriculum everything is, was, and always will be better than in the traditional curriculum. (The connotations of any such statement reflect negatively on the traditional curriculum.) Indeed, many problems were common with the traditional curriculum and the integrated curriculum presented itself as a vehicle towards the solution. This realization, in turn, together with student success in the pilot classes also increased administrative support. Almost
throughout, the support cycle was self-reinforcing. Increase in faculty support helped increase the administrative support and vice versa.

IIc. The College of Engineering and Science’s administrative structure.

We believe the curricular integration at Louisiana Tech University can be implemented independent of Tech’s special administrative structure. Yet the structure has facilitated effective communications and thus contributed to our overcoming of disciplinary boundaries. To give the reader an impression of the structure a brief description follows.

The College of Engineering and Science at Louisiana Tech University is comprised of the engineering disciplines plus mathematics, physics, chemistry, computer science and geosciences. In the mid-1990s the college underwent a major change in organizational structure to better support interdisciplinary work. Departments continue to exist as “programs”. Groups of two programs, which are normally closely related, are headed by an academic director. The academic directors, the associate deans for research and for undergraduate studies and the dean of the college form the leadership team. The leadership team aligns the budget of the college with the college’s strategic plan, which, in turn, is generated using extensive faculty input. Programs still handle program specific matters individually. Tasks important to all programs (such as recruitment, K-12 outreach, cross-disciplinary research, etc.) are handled by interdisciplinary teams of faculty. These teams make informed decisions that affect the future directions not just of their individual programs, but of the college as a whole. Each team has their own budget to be used to achieve the team’s goals.

III. Transition from traditional curricula to integrated curricula.

The main challenge any curricular innovation faces is the “mainstreaming phase”. Given success with pilot programs, the institution will have proof that the program is feasible, even successful at the present size, with the present personnel and with the present cohort structure. If the present size however involves uncharacteristically small class sizes and if the present personnel are the most dedicated teachers, then this does not allow the conclusion that the program will be successful when fully implemented. Moreover a pilot program normally does not offer “trailing sections”. This means that students who are unsuccessful in a class will leave the pilot program and be caught by the traditional curriculum. This makes for an uncharacteristic student body starting in the second term of the pilot program. From then on, all students in the pilot program will be students that passed all required classes the first time they took them. No repeaters from previous cohorts enter the group and unsuccessful students “vanish”. The special challenges to be faced in “trailing sections” are addressed separately in the next section.

Regarding class size we can say that starting with the second pilot group, class sizes were always near the 40 students that regular classes at Louisiana Tech University ideally have. This leaves the need for an increase in faculty participation to be discussed in this section.

The core faculty who designed the program undoubtedly were highly dedicated to education and made conscious career decisions (which could even be considered risky, given the current academic reward structure in the country) in their commitment to the integrated curriculum.
Because of the necessary communication between disciplines, the faculty workload in an integrated curriculum will always be higher than in a traditional, compartmentalized curriculum. The core faculty made a conscious effort during the design and pilot phases to minimize the extra work for faculty in the integrated curriculum. In some cases this meant to sacrifice some highly creative and beneficial activities for activities that were not as cutting edge, but which were more feasible and still provided solid education. For example, commonly graded examinations\footnote{1} are not part of the integrated curriculum. Instead faculty strive to weave connections from parallel and earlier courses into their course. This includes, for example, homework assignments in mathematics that include problems from the text of the parallel engineering class, or projects that relate to content from other classes. The (achieved) goal of the design was to provide a framework for curricular integration with some integration in place and further opportunities for integration available as the curriculum matures.

A gradual increase in the curriculum’s size seems most feasible once the design is in place, the college faculty is aware and approving of the integrated curriculum, and some new faculty are ready to enter the program. The original plan was a three-year phase-in period starting in the Academic Year 1999-2000. During this phase-in the number of participating faculty would increase as the number of sections offered is increased. Faculty would be trained in week-long summer workshops. “Trailing sections” would first be offered on a trial basis in the academic year 2000-2001. At the end of the phase-in period (summer 2002) the integrated curriculum would be the standard curriculum for all engineering majors and all programs would build their junior and senior level instruction upon the foundation of the integrated curriculum.

These plans needed to be adjusted when the Louisiana Board of Regents mandated in the Academic Year 1998-1999 that all degree programs in the University of Louisiana system had to be completed in 125 semester credit hours. To allow for ABET accreditation requirements this limit was 128 hours for engineering programs. Still it was a significant cut from the 135-140 hours that engineering curricula encompassed at the time. This mandate potentially required programs to set up a 128-hour curriculum based on the traditional curriculum, another 128-hour curriculum based on the integrated curriculum and a possible 128-hour curriculum for students in the transition period between traditional curriculum and integrated curriculum. Rather than tripling the workload of necessary curriculum redesign it was decided in all programs to speed up the transition and make the integrated curriculum the standard curriculum for all engineering majors starting in the academic year 1999-2000. In retrospect, the “crisis” of having to redesign all programs worked to the advantage of the institution. (For another description of how rapid introduction of an integrated curriculum appears to be more successful than a gradual increase, consider the successful program at the University of Massachusetts in Dartmouth\footnote{8,9}.) Suddenly, all faculty in all engineering programs had to confront the issue of curriculum reform. What was previously confined to the core faculty of the integrated curriculum became an issue of interest for everyone. The goals of the integrated curriculum design, especially the elimination of unnecessary duplication, were widely accepted. The fact that mathematics that students learned in 21+ hours in the traditional curriculum was taught in 18 hours in the integrated curriculum was another attractive feature.

Even without the mandate from the Board of Regents, hindsight (as well as the experiences at UMass, Dartmouth\footnote{8,9}) tells us that the rapid introduction of the integrated curriculum was more
appropriate than the originally planned gradual phase-in. Any adjustment to a new curriculum carries with it its own growing pains. A gradual phase-in only prolongs these growing pains and increases the danger that at some point the new curriculum ceases growing, leaving the institution with two competing undergraduate curricula. Few institutions have the resources to support two such curricula. Thus it appears preferable to commit all resources to change as soon as sufficient evidence supporting the change is compiled and as soon as enough faculty is ready to support the change. The short transition phase also reduces the time during which student cohorts from the traditional and the integrated curriculum coexist. Inevitably, advising and instructing two different student populations with different levels of preparation will cause confusion and dissatisfaction in faculty and students. For example, students in the integrated pilot programs sometimes complained they were working much harder than their nonintegrated peers. We shall show the flip side of this coin in the assessment section.

The rapid introduction of the integrated curriculum placed new demands on core faculty as well as new faculty. The main challenge was to have enough faculty available to teach all 240 incoming freshmen in the Fall quarter of 1999 plus later the expected trailing sections for students coming in from College Algebra and students running a victory lap in a course they enjoyed too much to move on. This challenge required an adjustment in the focus of the faculty and administration. The ability to teach freshmen and sophomores in the integrated curriculum became part of the hiring criteria for all programs. In mathematics, two new positions focussing heavily on the implementation of the integrated curriculum were generated and filled before the fall of 1999. Moreover it was decided that faculty new to the university should be spared a two-step adjustment, first to Louisiana Tech University and then to the integrated curriculum. Thus if new faculty teach freshman and sophomore classes, then these are integrated curriculum classes.

Even with new faculty coming to Louisiana Tech University, it was certainly necessary to have long-standing faculty participate in the integrated curriculum. To allow for more continuous information of faculty about the integrated curriculum the idea of a week long summer workshop was replaced by weekend workshops held Friday afternoon and Saturday morning. One workshop would be held each academic quarter for a total of three workshops per academic year. Participation in these workshops was and is voluntary and is rewarded with a stipend of approximately $150 per workshop. Topics included the overall design of the curriculum, curricular assessment, and the interface between the first two (integrated) years of study and the junior and senior years in which students specialize. The format is that one topic would be addressed in each workshop. Friday afternoon mainly consists of presentation of background information, the current status of development and some discussion. The Saturday morning session mostly consists of breakout sessions in which teams of concerned faculty will address specific challenges that were identified on Friday. At the conclusion of the workshop, the teams present their findings and discuss them with each other. This format has proved very successful. The solutions to faculty problems are most easily and appropriately found by faculty themselves. Moreover faculty more rapidly takes ownership of a curriculum in which they were part of the design or refinement process. The discussions were a natural vehicle that clarified for everyone that curricular redesign was a cooperative process. For example, prerequisite skills that students would not have when they reach “my course” would have to be taught on a just-in-time basis. Generally this need was offset by the realization that other skills would not need to be taught in the very same course. Faculty from all disciplines understood that the integrated curriculum

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would need to serve all programs. This meant that some specialized skills would need to be taught within the program rather than the integrated curriculum.

The new hiring as well as the workshops increased the faculty support and the faculty base for the integrated curriculum. This pool of faculty then had to be trained in facilitation of cooperative, technology-supported learning and in the integration between disciplines. Our main vehicle to do this was peer mentoring \(^3\text{,}^6\). The faculty teaching concurrent sections of the same course meets weekly or biweekly to discuss course-specific issues, teaching methods and integration opportunities. Mentors can share their experience, pass on class preparations and materials, etc. Moreover, the faculty of courses that are linked, such as the first engineering and mathematics class, will also meet biweekly to discuss issues that cross disciplinary boundaries. In these meetings possible content realignments that better facilitate integration are discussed. Also the faculty becomes aware of what is happening in the other classes, which allows them to connect content between classes. Occasional classroom visits, and frequent informal contacts, on topics ranging from a particular student’s difficulties to the design of exams round out the mentoring picture.

All the above allowed for the full implementation of the integrated curriculum in the academic year 1999-2000. This academic year was very demanding on the core faculty, as their expertise was needed in many places and often in several places at once. In the academic year 2000-2001 we are now seeing a gradual decrease in the demands on the core faculty, as new faculty take over more responsibility in the integrated curriculum. The challenges as well as tools for transition are outlined in Tables 3 and 4 at the end once more. A key challenge that lies ahead for the curriculum is the improvement of teaching of the “trailing sections” mentioned above. This issue is addressed in the next section.

IV. The difference between “leading” and “lagged” cohorts.

As was mentioned in the introduction, about 45% of Louisiana Tech University’s incoming engineering freshmen are not ready for pre-calculus and start in College Algebra. This cohort contains students with all the capabilities to become successful engineers. Louisiana Tech University draws most of its students from rural northern Louisiana. The reason for some students’ low placement in mathematics is that their high school did not have a mathematics teacher that would have been qualified to prepare these students even for pre-calculus. The cohort also contains nontraditional students returning to college, students that chose the wrong mathematics classes in high school and students who had the opportunities, yet still have low achievement in mathematics. The first integrated classes these students enter (typically in the winter of their freshman year after having passed College Algebra) are rounded out with students that started “on sequence” but failed a class (typically mathematics). Among the students that repeat the first mathematics class there is an equally wide range of backgrounds. Some students were overwhelmed by the adjustment to college. Though they tried hard, they were not able to manage their time adequately. Others may have been overconfident coming in and were surprised. Others yet appear simply over-challenged by the subject itself. This group of students, which may be the most diverse group of students in the College of Engineering and Science is what we will refer to as the “lagged cohort”. Lagged students have not been part of any integrated pilot program that we are aware of. They either never entered an integrated pilot
program or they were removed from it after the first term. Yet the accommodation of lagged cohorts in the integrated curriculum to us is the key challenge in full implementation. Isolated incidents of failure (especially during a challenging adjustment phase) or a slight lack in preparation should not prevent capable individuals from succeeding.

In contrast to the lagged students, the “leading cohort” consists of students that were eligible for pre-calculus or a higher class. Most of these students have seen parts of pre-calculus (even calculus) already and are often in limbo between pre-calculus and calculus. Calculus appears too much, pre-calculus appears too little. The integrated pre-calculus and calculus serve these students well, not only because the material is more motivated, but also because the better mixture of known and new material allows for a smoother transition into college.

The first offering of integrated classes to the lagged cohort was an eye-opening experience, likely because of the above mentioned differences between the cohorts. Essentially, almost all methods that teachers knew to work in the pilot program and with the leading cohort did not work. Overall motivation and capabilities were lower. Concepts that required no explanation previously now had to be discussed. Students did not react well to cooperative learning. In some, the expectation was that one would not need to work in class. Many of the “leaps of faith” that could be expected of students in the leading cohort did not occur. Questions that previously were answered quickly and led to interesting discussions now drew blanks.

Our assessment of the lagged cohort is in its beginning stages, so we will not be able to come to firm conclusions here. Yet the above has been observed by all faculty in all lagged courses. Some of it we conjecture to be a vicious cycle of attitude and preparation. Lack of good attitude, especially towards mathematics leads to insufficient preparation, which in turn influences the attitude. The attrition in the lagged cohort is higher than in the leading cohort. Yet it is not as easily observed, since every time the lagged cohort moves on, students that did not pass the next class fill in some of the slots previously taken by lagged students that did not move on.

To be sure, much of the attrition that is faced is indeed healthy attrition. Students that face problems often face them in several classes at the same time, which is a strong indication that the demands of engineering may make other career options more appropriate. In this, the integrated curriculum may have a benefit to marginal students, albeit it is a painful one. Marginal students realize early in their career that a switch to another discipline or an improvement in study effectiveness is needed to succeed. In contrast, in the traditional curriculum it was not unheard of that students would find loopholes that allowed them to take and repeat mathematics classes throughout their career at Louisiana Tech University. These students continued to hold the belief that they would become engineers one day and yet only very few ever finished.

Despite the somewhat negative experiences noted above, there is a genuine need for the lagged courses. Students that were unable to adjust quickly or faced a particularly challenging quarter can fall a quarter behind, though they have the capabilities to become engineers. Many of the problems listed above with the lagged cohort are lessened or have vanished in our first “leading lagged cohort” (students that failed exactly one class in the engineering or mathematics sequence or both). The first group of these students is taking the fourth quarter courses of the integrated curriculum in the winter quarter of 2000-2001 and data on this cohort will be available in winter.
2001-2002. Also, it needs to be said that some of the impressions of the instructors are subjective. An instructor who has extensive experience in teaching College Algebra is teaching Engineering Mathematics I for the first time in the winter quarter of 2000-2001. This instructor is impressed with the high (!) motivation and capabilities of the class. The effect is obvious, since only the top achievers in College Algebra enter the Engineering Mathematics sequence. With a good connection between the instructor and students often being a key factor to success, it might be appropriate to staff Engineering Mathematics I more often with College Algebra instructors than with instructors who have primarily taught sophomores in the leading cohort. The key will be to see how the lagged students perform in the long term and how they progress towards graduation. Standards will be held. Impressions can ultimately be adjusted.

V. Funding needs for the transition.

Funding needs vary greatly depending on what kind of program an institution wants to implement and also on how demanding key faculty will be for support. A hidden cost that made the integrated curriculum work at Louisiana Tech University is the dedication of the core faculty for the integrated curriculum. These individuals invested more time than the time they were released or paid for into the curriculum. Other duties, such as research, were postponed or curtailed to make this project work. Thus an underlying funding need that is hard to quantify is a reward structure that recognizes excellence in teaching and curricular innovation. This includes awards for these activities as well as administrative commitment recorded in tenure and promotion guidelines. Such adjustments in the reward structure are appropriate as long term educational demands on faculty time will remain. On the positive fiscal side, it can be said that given such a structure the extra investment in actual new funds can be relatively small. What we can describe are the costs encountered by Louisiana Tech University, which we believe are low in relation to the large scope of integrating the freshman and sophomore years. For institutions of other sizes, costs need to be scaled, though it is not clear if these costs scale in linear or super-linear fashion.

Va. Start-up costs.

Development of the first integrated curriculum pilot program was funded by a $20,000 grant from the Chevron foundation. These funds paid for summer salary of some core faculty that designed the integrated freshman year. The sophomore year was designed during the first year of the pilot phase, as part of the service duties of some faculty members. The newly hired core faculty member invested two courses worth of release time (written into the incoming contract) into the development of the integrated sophomore year and the teaching of an integrated freshman class.

Core faculty sought funding for design and piloting of the integrated curriculum from the Louisiana Board of Regents, obtaining two grants of approximately $25,000 each for equipment, summer salary and travel to education conferences. These grants were matched by three courses release time for each faculty member. Time was used to develop classroom materials such as, for example, a supplemental set of notes on differential equations and statistics and projects for a statics class.
This funding allowed for the full design and piloting of the mathematics sequence as well as the first four engineering courses by faculty that consistently went above and beyond the call of duty. We estimate that, with highly dedicated faculty and strong administrative support, over a period of two years, a total $100,000 in funds for equipment, travel, and summer salary, plus a total of at least 10 courses in release time, should be sufficient to fully design and pilot an integrated curriculum for the freshman and sophomore years. After this design and pilot phase a consensus whether to fully implement has to be reached in the college. Assessment is the key in this step. The challenging part is to gauge if curricular integration has the chance of becoming a part of the institutional culture that can largely carry itself. Large scale buy-in, which makes curricular integration a process that is self-reinforcing, is mandatory. If this is given, one should move forward with the implementation. If (stiff) resistance is faced, a longer pilot phase with additional investments, or cancellation of the project, are in order. The potential gains of the project are well worth the initial investment, even given the risk of failure.

Vb. Transition costs.

These costs are the largest single item in the implementation of an integrated curriculum and they also include holdover costs from the design and pilot phase. During the transition phase further needs for materials will arise and the overall structure that is set up in the design phase will need to be fleshed out. Mentoring and workshops will require faculty time. There need to be stipends for faculty workshops. Facilities that allow for cooperative, technology-supported learning may need to be constructed or duplicated. Most of these costs were provided by an Action Agenda grant from the National Science Foundation and by matching funds from the university and private donors. All figures that follow are investments over a 3-year period. Most of these investments will be in the initial year of full implementation.

The most important investment is again in the people who carry the curriculum. There is a continued need for release time for the core faculty as well as summer salary to continue the development of curricular materials, mentor colleagues, hold workshops and intensify assessment activities. We estimate a total of $200,000 over three years in summer salary plus at least 15 courses release time for these purposes. Equally important is the increase of professional development for core faculty and new faculty. Our estimate is that $30,000 for travel to education conferences for new faculty and to assessment conferences for core faculty would be appropriate. The most effective component of our implementation may be the Friday afternoon-Saturday morning workshops. The main costs are stipends and food for the participants. Our estimate is a total cost of $40,000 for these workshops. The communication and buy-in achieved through these workshops is well worth the investment, though it sometimes appears as if one merely “pays people to talk to each other”.

Facilities can be purchased as needed. All of the activities implemented at Louisiana Tech University need the personnel first and foremost and facilities second. Yet it has to be said that the traditional classroom or computer laboratory environment is not conducive to cooperative, technology supported learning. Furniture is hard to group and, once it is grouped, the instructor may not be able to easily reach the groups and communicate with them. Moreover in a traditional computer laboratory the machines have an overbearing presence that isolates students from each other and that almost demands the use of technology independent of whether it is appropriate or
not. Louisiana Tech University built two multipurpose classrooms in which students sit at tables in groups of four. Each table has connectivity for four laptop computers and two laptop computers per table are provided. (The ultimate goal is for students to bring their own computers to class.) Cabinets hold equipment for small in-class experiments and projects, including digital data acquisition systems. This setup was first observed by Louisiana Tech faculty at Texas A&M University. The total cost for renovations, furniture, computers and experiments was approximately $300,000 for two classrooms that seat forty students each. These funds came from the mentioned Action Agenda grant, a grant from the Louisiana Board of Regents and from private donations.

Vc. Long-term costs.

Ideally (in a fiscal sense) the long-term costs would be the same as for the traditional curriculum. This hope, however, has to be abandoned considering that the time overhead for communication between classes and adjustments in teaching are permanent. The more ambitious the integration, the higher the overhead. ABET requirements for continuous feedback, and improvement of curricula, suggest that part of this overhead will be encountered by institutions regardless of integration or not. In this sense curricular integration can become part of the accreditation process and two issues are addressed with one cost that is less than the sum of costs for both. The required faculty time, which may affect research productivity is hard to gauge at this stage, but it will have an impact.

Maintenance of new lab facilities will be comparable in cost with maintenance of existing facilities and can be estimated in this fashion. With respect to computer labs, the largest cost is the continuous need for upgraded equipment. This cost can be curtailed by requiring students to purchase their own laptop computer to bring to class. Even at an institution such as Louisiana Tech University that serves students who often cannot afford very much beyond tuition this requirement is under discussion. The main guideline would be to make the total package affordable for the students. If the institution is freed from the need to upgrade equipment destined to be obsolete, then funds can be invested in infrastructure as well as programs that give economically disadvantaged students access to technology.

As a new budget item the main long-term cost foreseen at Louisiana Tech University is the continuation of the Friday afternoon-Saturday morning workshops. We envision a reduced schedule, say two workshops per year instead of three, and possibly smaller stipends if this is feasible. The format of “paying people to talk to each other and build a better institution” has been so successful that administration has made this step a distinct possibility. Regular feedback and communication are essential to keeping such a widespread curriculum viable. The estimated cost for the workshops would be approximately $10,000 per year. Again, with properly set agendas and effective follow-up activities these costs will be more than recovered when accreditation becomes an issue.

VI. Assessment techniques to measure impact of curriculum reform.

No single assessment method will give the answer to whether a given curricular innovation is successful or not. Yet different methods will carry different weight with parts of the constituency
(faculty, students, parents, administration, alumni, employers). Moreover if in a variety of qualitative and quantitative assessment methods all indicators show the integrated curriculum to be an improvement, then one has sufficient grounds to believe this is true. We shall address qualitative and quantitative methods here.

VIa. Quantitative Assessment.

Obtaining success data of students in a pilot group compared to the regular students is a vital first step in moving towards curricular change. An excellent model how to set up equivalent cohorts to measure the impact of curricular reform was implemented at UMass, Dartmouth.\textsuperscript{8,9} Our first pilot group was self-selected, which means that students may have had slightly better preparation and higher motivation. The small size of the incoming class did not allow for a structured cohort setup with the second pilot group (essentially all eligible students were integrated). While this can be considered a mistake, cohort comparisons are still possible using institutional data.

Our first comparisons were between integrated classes and their nonintegrated counterparts. In all cases more students were successful in the integrated classes than in the nonintegrated classes. Yet this may not be surprising as we are comparing classes made up of engineering students with classes that are not as homogeneous. Moreover, as mentioned, the first pilot program may have started with a better student cohort, and after the first term only the best of these students progressed. Especially the filtering effect also remains valid for the second pilot group, and again higher success rates were achieved in all classes.

In one case in the pilot phase a faculty member taught comparable integrated and nonintegrated classes and performed an item analysis of comparable or equal test items. Again the comparison was in favor of the integrated classes. More detailed item analysis and administration of comparable tests to comparable cohorts certainly is recommendable in the piloting phase if possible.

It was possible to identify a cohort that could be comparable to the first integrated pilot group. For us, this was the group of students who entered engineering “ahead” in their mathematics classes. That is, we chose a group of students who in their first quarter were able to take a mathematics class that was higher than the first pre-calculus class. This cohort was about the same size as the first pilot group (40 vs. 39) and had a comparable average ACT score (about 28). Since the integrated pilot group contained a number of students who would not have been eligible to skip a mathematics class, we consider this comparison actually biased in favor of the traditional curriculum. The integrated students on average attempted 5 more credit hours in their first three years and completed about four more credit hours while maintaining a comparable GPA.

On-time completion of prerequisite classes is a much needed foundation for success later on in the curriculum. Therefore we analyzed the progress of these cohorts through the mathematics, physics and chemistry classes in the first two years. Both these groups could be expected to have completed their mathematics sequence within their first six quarters. The same number of students completed their mathematics sequence within the first six quarters. When considering completion of all core classes (math, physics, chemistry) within a given time frame the integrated
students even have an advantage. 30% of the integrated students finished mathematics within the freshman and sophomore years, and physics I and chemistry within the freshman year. This contrasts the 22% of the nonintegrated group which finished mathematics within the freshman and sophomore years and physics I and chemistry within the first four quarters. We allowed a more generous time frame for the nonintegrated students because of the previous curricular structure. If we use the timetable of the integrated curriculum the 22% drops to 2.5% for the nonintegrated students.

For a comparison of the progress through mathematics for these and several other cohorts, please consider Table 5. Unsurprisingly, the students who started ahead in math had an advantage in math. Overall, the above and Table 5 show that integrated students progressed faster through the curriculum than the possibly best of the nonintegrated students. Moreover, the cohort that was eligible to skip a math class provided the majority of nonintegrated students that completed their mathematics requirement within seven quarters. This explains the favorable numbers in Table 5 when all integrated students are compared with all nonintegrated students. This also explains integrated students’ complaints about having to work very hard. They compared themselves to students who entered at the same time as they, but who were rapidly falling behind. The high success for the first integrated pilot group is likely related to their self-selection for this curriculum (above average motivation, preparation). Lower success for the second pilot group as well as the fact that in the pilot groups most students who finished math in less than 7 quarters finished it in 6 quarters are probably because for these groups no “trailing sections” were offered. The numbers for students who entered in Fall 99 are conservative projections based on current enrollment in the appropriate mathematics classes. Even these conservative projections show that the integrated curriculum is more successful in keeping students “on track”. This should result in better preparation for later classes and consequently higher retention and graduation rates.

Within the transition phase we analyzed “blended” classes that included integrated and nonintegrated students (second pilot group). These classes were typically core engineering classes that had to be taken by integrated and nonintegrated students. Across the board, integrated students outperformed nonintegrated students by about 10 percentage points on the final average grade in these classes. In some instances such classes had one section of mostly integrated students and another made up of nonintegrated students. The sections with integrated students normally outperformed the nonintegrated sections (one instructor finished an integrated section a week ahead of the nonintegrated section that he also taught).

Finally, cohorts graduating in engineering in four years have traditionally been small at Louisiana Tech University (<40). In our current first fully integrated cohorts we expect 60 students to complete all core requirements (math, physics, chemistry) within their first six quarters and an additional 30-40 students to complete their core requirements within their first seven quarters. This should leave us (after the fall of 2001) with a cohort of about 100 students that are on track to graduate in four years in engineering. This is more than twice the number of students we normally had in this position. If this prognosis holds up, integration was a strong boost to retention. Firmer long-term retention data will be available after spring 2003.

As a measure of faculty involvement we can report that by winter 2000-2001 about 35% of the faculty in the college have taught courses in the integrated curriculum. If we take into account
that some faculty are not eligible to teach these courses (research appointments, programs that do not participate, commitments to service courses), we have close to 60% of all possibly eligible faculty involved.

VIb. Qualitative assessment.

Equally important as the statistics above is the assessment of attitudes of students and faculty. To this end, assessment consultants were hired to conduct surveys and focus groups. These studies showed that none of the surveyed students and faculty believed the integrated curriculum to be less demanding than the traditional curriculum. Moreover there was strong agreement to the statement that integrated students are better prepared for junior and senior level engineering classes than students in the traditional curriculum.

Analysis of syllabi and course objectives supported the above statements. The same (and in some cases more) content was taught in the integrated curriculum. Performance of integrated students in later classes supported the observation that integrated students were better prepared.

Because of small numbers the effects on women and minorities have so far been measured qualitatively only. Female integrated students and female nonintegrated students were interviewed separately and transcripts were compared. Female integrated students were less hesitant to interact with (typically male) engineering faculty earlier in their careers. Group activities in class also allowed them to form professional relationships with their male peers earlier than this occurs in the traditional curriculum. Integrated female students believed that the integrated curriculum helped them develop leadership skills. This is despite the fact that, at first, male students expected to take the lead in group work and to have females “do the writing”. One factor that faculty sees as positive for women in the integrated curriculum is that there is a critical mass of female peers (that is, female engineering students) in every class. In the first two years of the traditional curriculum this was not the case.

Groups of integrated and nonintegrated minority students were interviewed in the same fashion. The perceived gains through the integrated curriculum for the minority students were not as high as for the female students. One contributing factor here could be that minority students form the smallest cohort in the engineering curricula. A challenge for recruitment is to provide a critical mass of minority students to allow for the same improvements as for female students. Neither group described any aspect of the integrated curriculum as a step backwards. The difference was in the size of the perceived gains.

Despite possible imperfections in any of the methods we used, the overall verdict is undeniably in favor of the integrated curriculum. Every indicator we chose showed better (or at least equal) success in the integrated curriculum. A future task will be the measurement how much the integrated curriculum still depends on the initial core faculty. Complete success will only be achieved when the curriculum has reached a stage at which all core faculty could walk away and the curriculum would still function. We are targeting to reach this stage by Summer 2002.
VII. Methods to enhance integration between courses.

Essentially these methods have already been mentioned above, so we merely need to re-emphasize their importance. First, one needs a curricular structure that allows for integration to take place. If students are allowed to take, say, a circuits class before they know anything about differential equations, then an opportunity to connect mathematics and engineering is wasted. Also note that our structure shows that it is not necessary for students to have taken a whole course in differential equations.

Second, one needs faculty to be aware of the cross-connections between the courses. This awareness is seeded in workshops as we described and reinforced through mentoring and regular meetings with faculty teaching the other courses. The underlying philosophy has to be that faculty should continuously look for more and better connections.

Third, one needs formal connections. These can be manifested through classroom materials and assignments (homework, projects, exams) that refer to the other classes.

In our experience, the most important component is the awareness of what occurs in other classes listed as our second point. This is the stage at which most of Louisiana Tech University’s efforts currently are focused. Faculty that have progressed beyond this stage are now working on increasing formal ties as described in our third point.

VIII. Impact on curriculum improvement at the junior/senior level.

The immediate impact we observe is that (if our assessments are correct) students are better prepared for the junior and senior level classes once they have completed the integrated curriculum. If the scope of the integrated engineering curriculum stopped here, then we would not obtain the maximum benefit. Dialogue with faculty that typically teach junior/senior level classes has been started to allow for better use of the skills that students have acquired already. There simply is no point in teaching students how to write a lab report if they have already written (presumably good) lab reports for a year. Similarly, the teaching of skills in basic statistics and basic lab skills that previously could not be taken for granted and were duplicated throughout junior level courses can now be replaced with deeper exposure to the specialized fields students enter in their final two years.

The above requires a redesign of junior and senior level courses which has just started at Louisiana Tech University. Eliminate any newly arising duplications, replace them with skills that may not be present in the integrated curriculum on a just-in-time basis and produce a better prepared engineer than before. An awareness of what can realistically be expected of students is currently replacing previous attitudes that students should be exactly how faculty wished students to be. Existing student skills are appreciated and holes in their education are not bemoaned, but filled as needed.

Essentially the above is the final stage of curricular integration and reform. Challenges and adjustments similar to the introduction of the integrated curriculum lie ahead.
IX. Conclusion.

Overall, the introduction of the integrated engineering curriculum has been successful at Louisiana Tech University. The new structure is solid enough to stand on its own and provides the framework in which further ties between disciplines can grow. Faculty participation and buy-in are near long-term sustainable levels. Students entering today are expected to be more successful and better prepared than students who entered in the traditional curriculum. The present course structure is shown in Tables 1 and 2. For a summary of barriers and mistakes, cf. Table 3 and for a summary of tools used cf. Table 4. Some data on student progress is given in Table 5.

<table>
<thead>
<tr>
<th>Table 1. Freshman Year Course Sequence.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>First Quarter</strong></td>
</tr>
<tr>
<td>---------------------------------------</td>
</tr>
<tr>
<td>ENGR 120, engineering profession,</td>
</tr>
<tr>
<td>study, teaming, problem solving skills</td>
</tr>
<tr>
<td>pre-calculus and calculus</td>
</tr>
<tr>
<td>Chemistry 100, measurement, atomic</td>
</tr>
<tr>
<td>symbols, chemical formulas</td>
</tr>
<tr>
<td>English 101, composition I</td>
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</tbody>
</table>

<table>
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<tr>
<th>Table 2. Sophomore Year Course Sequence.</th>
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<tbody>
<tr>
<td><strong>Fourth Quarter</strong></td>
</tr>
<tr>
<td>---------------------------------------</td>
</tr>
<tr>
<td>ENGR 220, Mechanics: statics and</td>
</tr>
<tr>
<td>strengths of materials</td>
</tr>
<tr>
<td>Engineering Math IV, Basic statistics,</td>
</tr>
<tr>
<td>multivariable integral calculus</td>
</tr>
<tr>
<td>M&amp;MSc 201, Materials Science</td>
</tr>
</tbody>
</table>

The remaining coursework in the sophomore year is controlled by the programs. To avoid scheduling problems, Materials Science and Physics 202 are optional in some programs.
<table>
<thead>
<tr>
<th>Barrier to overcome, or mistake made</th>
<th>Corrective action</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Administration cannot mandate change, isolated individuals cannot change a whole university.</td>
<td>Identified interested individuals with leadership potential, charged them with development of the curriculum, gave them near total freedom for the design.</td>
<td>Dedicated core faculty that have full support of the administration.</td>
</tr>
<tr>
<td>Bottlenecks in the curriculum, often manifested in student complaints about high workloads.</td>
<td>Assessed if the workload truly was unreasonable. If so, restructured content and assignments as appropriate. If necessary, eliminated parts that appeared to increase the workload without improving the instruction. Considered the whole structure, to avoid creating a new problem as the current problem is addressed.</td>
<td>While students still have peaks and valleys in their workload, they are smoother than before. Faculty are able to deliver instruction unhindered by external factors such as student exhaustion.</td>
</tr>
<tr>
<td>Possible suspicion that “the new curriculum” endangers long held standards, places undue demands on faculty, etc.</td>
<td>“Open” design, pilot and implementation process. As soon as data became available it was presented or at least made available to the whole college. Concerns from “outside” faculty were addressed. Sought ideas from “outside” faculty at appropriate places in design, pilot and implementation.</td>
<td>Actual information (favorable or not) replaces guesses. Faculty aware that not all is well, but problems that looked unsolvable before are addressed and some are solved.</td>
</tr>
<tr>
<td>Pilot programs can become isolated from the rest of the college.</td>
<td>Constant updates and communication. Rapid upgrade of the integrated curriculum from pilot program to being the regular curriculum.</td>
<td>Broad faculty awareness. More intense growing pains, but also better success through a shorter adjustment phase.</td>
</tr>
<tr>
<td>Transition phase involves redesign of programs and a divided student body.</td>
<td>Shortened the transition phase and implemented the integrated curriculum as quickly as appeared prudent.</td>
<td>Shorter time-span in which “growing pains” is present.</td>
</tr>
<tr>
<td>How can broad faculty buy-in be achieved?</td>
<td>Included all interested faculty in the refinement and implementation phase of the integrated curriculum. Held informative workshops in which “outside” faculty contributed to solutions just like the core faculty.</td>
<td>Solutions are found that the original designers may have overlooked. The interface with upper level courses becomes more efficient. Faculty takes ownership.</td>
</tr>
<tr>
<td>Faculty base too small at the start of full implementation.</td>
<td>Concentrated effort on mentoring faculty new to the curriculum. Active recruitment of Tech faculty and new hires into the integrated curriculum Adjustment of reward structure to include quality teaching and educational innovation.</td>
<td>Faculty base increases at a steady pace. Research remains important, but it is no longer everything.</td>
</tr>
<tr>
<td>Underestimated the different climate in “lagged classes”.</td>
<td>Upheld standards and demands. Analysis of how to better serve this population started.</td>
<td>Lagged classes are still “different”. Data on lagged cohorts will soon be available.</td>
</tr>
<tr>
<td>After implementation at freshman and sophomore level, junior and senior levels have to adjust.</td>
<td>Process started in Fall 2000.</td>
<td>Anticipate adjustment to a deeper junior and senior curriculum by 2002.</td>
</tr>
<tr>
<td>Content integration could still be improved as possible connections are currently not exploited.</td>
<td>The design was to provide a framework for integration, not the last word on it. Faculty is encouraged to explore new avenues, to test, implement and share them.</td>
<td>Continuous improvement process.</td>
</tr>
</tbody>
</table>
Table 4: Key tools/actions and their effect.

<table>
<thead>
<tr>
<th>Tool or action</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial design left to small group of faculty who remained in contact with the college while designing the curriculum.</td>
<td>Efficient design process.</td>
</tr>
<tr>
<td>Weekly meetings of faculty involved in teaching the same student cohort.</td>
<td>Awareness of correlated content as well as (individual) student difficulties.</td>
</tr>
<tr>
<td>Mentoring of faculty new to the integrated curriculum.</td>
<td>Smooth transition of faculty into a new teaching environment.</td>
</tr>
<tr>
<td>Friday afternoon, Saturday morning workshops that blend presentations with input from all faculty.</td>
<td>Strong faculty support and broad based sense of ownership. Better solutions to problems that were addressed.</td>
</tr>
<tr>
<td>Ability to teach in the integrated curriculum as a recruitment criterion and part of the reward structure.</td>
<td>New faculty are not surprised by teaching demands. Faculty remains assured that a (perceived) shift in focus will not have adverse effects on their career at Tech.</td>
</tr>
<tr>
<td>Multiple assessment measures (qualitative and quantitative)</td>
<td>Possible problems can be triangulated. Largely positive results from all tools are a boost to the implementation.</td>
</tr>
<tr>
<td>Though implicit in some of the above: efficient communication between all involved constituencies.</td>
<td>Few misunderstandings, if any. Potential problems often addressed before they arise. Actual problems resolved quickly and relatively painlessly.</td>
</tr>
</tbody>
</table>

Table 5: Progress of various cohorts through the curriculum.

<table>
<thead>
<tr>
<th></th>
<th>Enter Fall 97, nonintegrated, math head start</th>
<th>Enter Fall 97, nonintegrated overall</th>
<th>Enter Fall 97, integrated pilot group</th>
<th>Enter Fall 98, integrated pilot group</th>
<th>Enter Fall 99, integrated curriculum is mandatory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Math done in 6 quarters</td>
<td>35.0%</td>
<td>11.1%</td>
<td>35.9%</td>
<td>18.5%</td>
<td>~25% (projected)</td>
</tr>
<tr>
<td>Math done in 7 quarters</td>
<td>45.0%</td>
<td>17.8%</td>
<td>35.9%</td>
<td>19.3%</td>
<td>~35% (projected)</td>
</tr>
</tbody>
</table>

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