What math do we really need?

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Abstract

The Microelectronics program in the Technology College at ASU was totally restructured in 2001. The courses are entirely new and have novel (web + class) delivery arrangements. There has also been substantial industry input both for planning and contributions in the class-room. As a result, we have been able to execute a strategy that aligns the skills and capabilities of the graduates with the starting requirements of our 12 supporting companies. The next stage is to "pull" the skills needed by the senior-level courses from the lower division and feeder programs.

On that basis, we have analyzed the math used in two microelectronics courses:

1. UET416 – Dopant control technology. This covers transistor operation, ion implantation of dopants and diffusion in subsequent thermal processing steps. It has everything from differential equations to statistical control and no matter the university where it is given, the topic has a strong traditional math content.
2. UET417 – Clean room practice. The primary goal is to ensure safe working conditions. The scope includes effective communications and reporting with the typically diverse range of data encountered in any high-tech industry.

Every math instance in almost 1000 slides has been classified. The results show a strong emphasis on problem and solution representation.

1. Rationale for the analysis

Any discussion about the math skills required by engineering students is guaranteed to be lively. It seems to be one of these eternal debates, perhaps because it has so many dimensions. Some of the main issues are:

- We practice a profession which is built on mathematical representation coupled with data for validation and analysis.
- We have an organizational "build or buy" option. Most departments see-saw between providing their own math courses and farming them out to the specialist math departments.
- In a world of rapidly changing technology, the basics are constant. That gives comfort to some, especially when allied to the more subtle desire to preserve a measure of elitism in a mass education market.

- Any group of practicing engineers will readily admit that in their entire careers they have used only a very small proportion of their math skills.

Each of these points has enough validity to guarantee endless discussion but the driver behind this little project is more pragmatic. We wish to have a compact competency statement for the math skills of our graduates. We have competencies and outcomes for all the mainstream electronics subjects but for math, it is just a statement of the topics studied. That is not enough. We need to know if a student can USE the math knowledge in a typical job context. Our senior-level courses can provide an approximation to that application space so we have started by analyzing two representative courses. To avoid the trap of becoming too narrowly specialized, we also looked ahead to the factors that are driving changes in job functions. The objective of the project described in this paper was therefore to quantify how we use math and then develop a classification system that prioritizes essential skills in an objective and transparent way.

At ASU, we have an educational system that accepts students from diverse backgrounds. Limited resources of faculty and course time have to be matched to an output that meets the needs of a dynamic industry that has global development options. Figure 1 represents the input-output constraints.

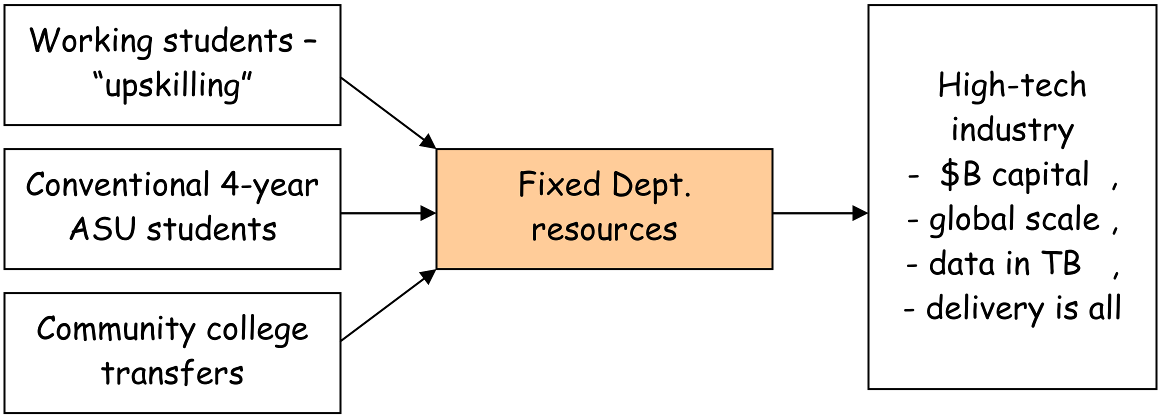


Figure 1 Balance input diversity with output focus

With a good graduate competency statement, we are better able to advise our feeder institutions on essential skills, especially in math and basic sciences. They in turn can use our information to develop their courses and give examples of practical applications.

2. Reference to industry competencies

In 2001, the Microelectronics program in the Technology College at ASU started to undergo a total restructuring process so that it would more closely match current and future industry needs. Production of semiconductor components is a major industry segment in Arizona with a direct workforce of over 30,000 plus a larger number providing services and support. The heart of our approach is a close interaction with all the major local companies for strategic advice, a first employment destination for graduates and a role in life-long learning for the workforce. Specifically:

- We have a strong Industry Advisory Board composed of senior managers. There are monthly meetings of the Board or one of the working groups.
- About half of every senior class is composed of students who are working in one of the major companies. They are usually following a qualification upgrade path so their experience and motivation are powerful inputs.
- The concentrated whole-day class sessions make it easy to feature embedded seminars from industry specialists. They too receive all the preparation materials so everyone has the same baseline.

One of the principal outcomes from this process is that we quantify the ways in which the "essential personal skills toolkit" is changing. Formerly, every engineer had to be able to work through all aspects of a solution, including the appropriate closed-form math. Now, with extensive design automation tools, vast databases and a network that reaches every desktop, we have a very different scenario. The factors driving change are:

- The requirement to continuously produce "more for less" [1]
- The technology implications of Moore's Law laid out in the International Technology Roadmap for Semiconductors [2]
- Operation on a global scale with diverse market needs
- The volume of data within the personal domain of engineers in the semiconductor industry has risen from MB to TB in 20 years
- The 6σ axiom to "get it right first time" and have the data to prove it.

As a result, jobs in high-technology companies seem to be developing into two categories: specialists and integrators. The former have sophisticated simulation and analysis tools and can be viewed as internal consultants. The integrators are technologists who use their real-time knowledge of local events to formulate solutions that are objective and business-oriented. The implication is that expert help is available from the specialists provided both parties can communicate effectively. This usually means expressing evidence in some format that involves data or a relationship between physical variables. The biggest challenge is usually to formulate the problem. Thereafter, we have the experts and tools to find a solution – but it can only be as good as the specification.

Although this little project has been exclusively concerned with the use of math in an electronics context, we have affiliations with several large aerospace companies and automotive hot weather testing. Both groups seem to have very similar requirements for math skills and a wider review in the future should map and compare their requirements.

3. Process for data collection

With a sound appreciation of workplace skills and competencies, the next step was to undertake a gap analysis to see how the outcome from the lower division educational preparation process matched the specialist applications (figure 2).

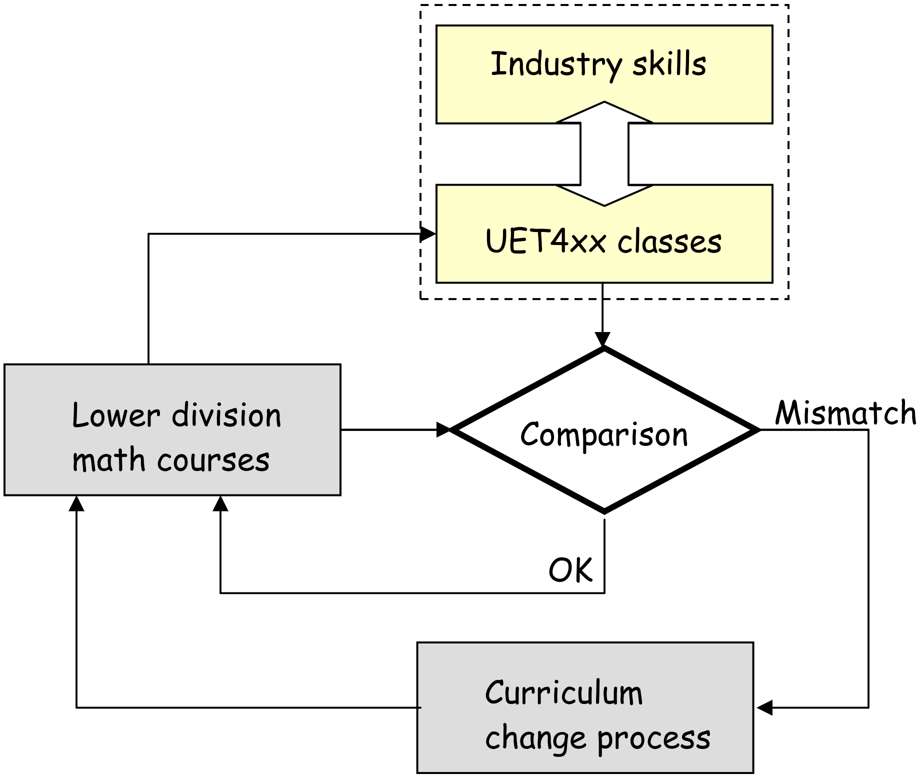


Figure 2: Process for skills gap analysis

This paper describes the first stage of the comparison process - a classification of the math skills required for two representative Microelectronics courses.

The task was simplified by having all classes available for web-supported delivery. That allows classes to be delivered in a compressed format with an intensive whole-day class backed up by 100 or more slides and reading materials available in advance on the web [3]. This arrangement suits working students but it also allows a focused discussion on points of difficulty that emerge from the preparation efforts. Reports and exams also provide conventional but less immediate feedback on progress.

The first plan was to use the math classification employed by the Arizona Department of Education (AdoE) for its vocational technological curriculum [4]. While the list provides a good starting point and easy linkage to high school graduation standards, it has two serious drawbacks:

- There are 269 categories, with many overlaps. An unwieldy list.
- We need university-level math as well.

Using the concepts in the ADoE list and the ASU math curriculum, we have developed a more compact skills list under 4 headings:

1. Fluency in basic operations	2. Set-up the problem
Arithmetic Algebra Trig functions Exp/log Vectors Complex numbers Differentiate Integrate Use spreadsheet Use dedicated tool	Define requirements Linear relation Polynomial or other Represent 2 dimensions Represent 3 or more dims Diff equation Appropriate units Statistical distributions Boundary conditions Sanity check
3. Calculate or compute an answer	**4. Present answer in best format**
Evaluate algebraic equation Solve diff equation Compute areas/volumes Statistical moments Measure Test for significance Extract coefficients Sanity check	Estimate Numbers & units Equations Graph Diagram Appropriate scales Appropriate accuracy

Based on experience of its application, this list seems to be sufficient for the purpose. Reduction to 33 categories certainly makes the classification process more manageable.

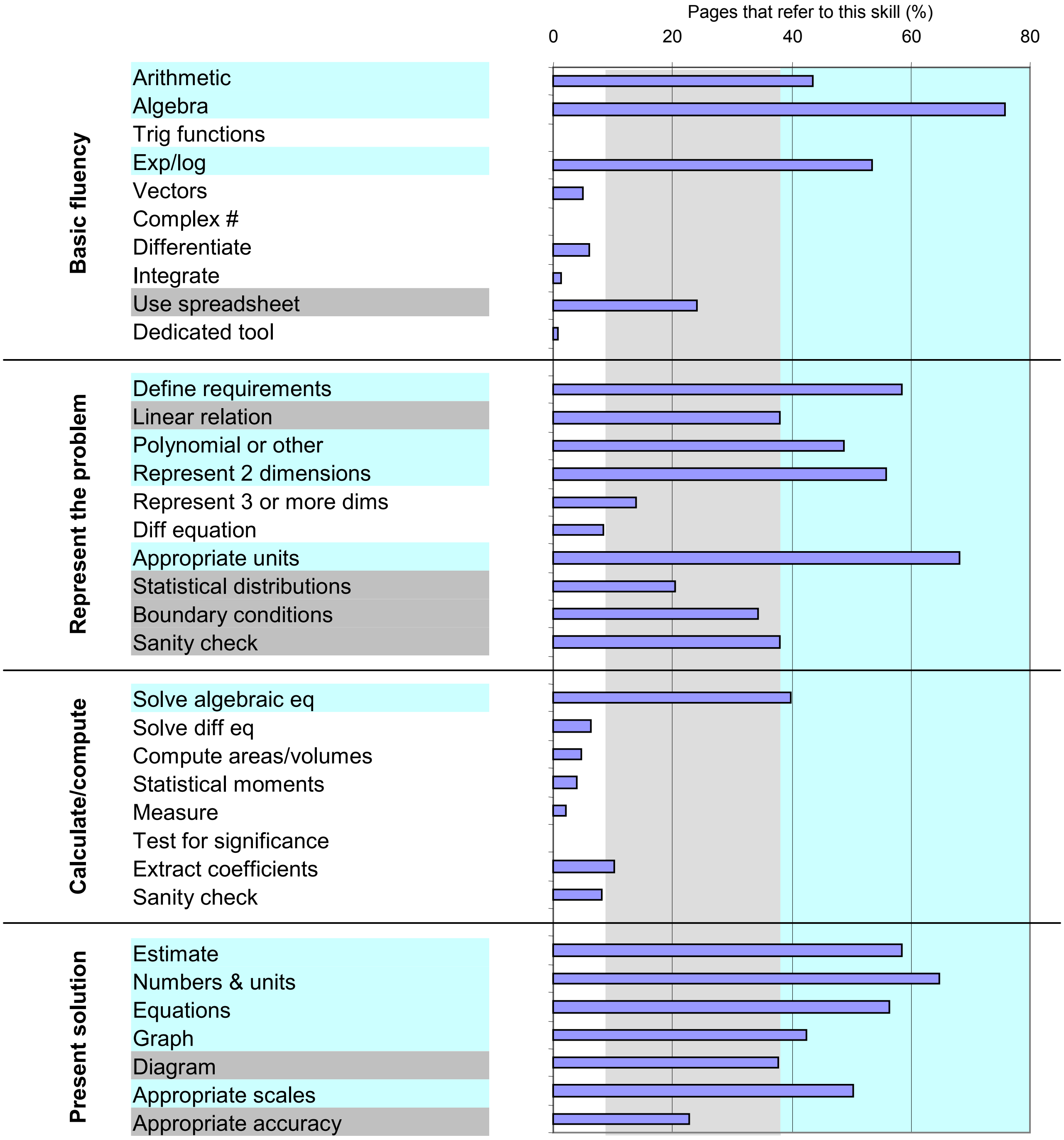
Two courses were selected for detailed evaluation:

- UET416 – Dopant control technology. This covers the requirements that can be derived from the design of transistor structures, ion implantation as a doping technique and diffusion as a process that can alter the final dopant profile in any device. It covers a wide range of math features, from very sophisticated representation of charge and ion movement to the physics of ion acceleration and diffusion.
- UET 417 – Clean room practice. This course deals with the competencies required to work in a clean room, including safety, factors that determine yield, structure of complex process tools and data collection practice.

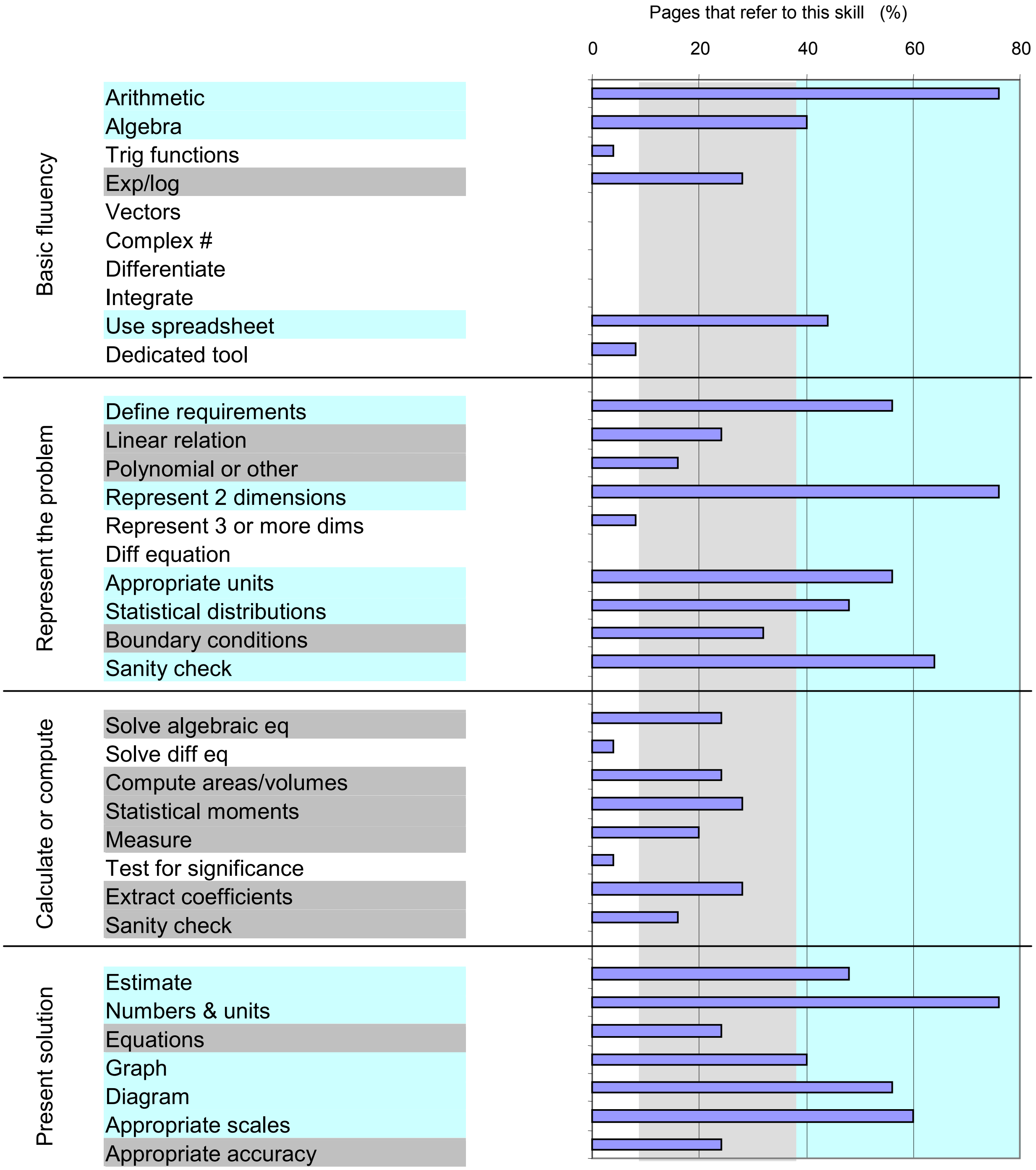
Both courses are targeted at the same levels of technology and they share similar presentation arrangements. Students receive class notes (in Word and Powerpoint) and background papers 2 weeks ahead of each class. From these, they have to undertake preparation assignments that are submitted the day before each class. The process works well for class dialog but it presumes a base level of competency in the underlying science and math. By mapping out the required skills for every part of the course, we hope to be able to improve student preparation in lower division courses and also devote more time to filling any uncovered gaps.

4. Results and analysis

The tabulated summary for UET 416 (Dopant control technology) shows the frequency of use of each math skill. The incidence has been roughly coded into 3 bands.



The tabulated summary for UET 417 (Clean room practice) shows the frequency of use of each math skill. The incidence has again been roughly coded into 3 bands.



To make comparisons easier, the data has been normalized. That requires selection of a base-level and for both courses, it was the number of pages that contained a presumption about the ability to use the appropriate math skill. As might be expected, the practice-based course had a smaller number of pages that were counted. The numbers are shown in the following table:

UET 416 Dopant control technology	
Total slides	642
# with math content	236
% used	37
UET 417 Clean room practice	
Total slides & pages	329
# with math content	25
% used	8

A more subtle distinction was that the dopant class used math pervasively as a means of presenting the technology whereas in the practical class, all the math was highly focused into a few measurement-intensive activities.

5. Comments and conclusions

The results from the two courses are remarkably similar, considering the differences in their scope and technical content. This may confirm a level of consistency in the preparation and presentation of the material (to be expected since both courses were developed by the same person) but there are three other significant outcomes to emphasize.

Both courses presume total fluency in handling numbers and basic algebraic functions. No surprises so far - but there is a distinct absence of higher-level math functions (except log/exponential). Calculus hardly appears in its usual closed-form format despite being the central feature of any conventional treatment of diffusion. The reason is not hard to find. The calculus we see in every textbook is an idealized representation that offers little insight into a solution for realistic boundary conditions. The professional world has moved on. We now have to select one of two options: to linearize the whole problem and find a quick, coarse solution or else use a sophisticated simulation tool that gives a numerical solution of the differential equations. The latter is usually the province experts. The goal of the course is to provide a general understanding of the key features and dependencies for the technology and for that goal, the simple linear approach works well. Simulation of charge flow in transistors and ion distribution is a specialized topic for a more advanced course that is currently being developed.

The second major outcome is to note the emphasis placed on mathematical representation of problems and how the solutions can best be presented (categories 2 and 4). This will come as no surprise to anyone familiar with the day-to-day engineering activities in a company. However, it is at odds with the traditional way we teach math. Students are invariably taught how to solve specific math problems. They are well-drilled in these solutions but are rarely shown how to translate events into a mathematical format that can be solved. As a result, when faced with a new problem, the first recourse for most students is to try to recall a similar problem, become confused and spend a lot more time struggling with the math than the validity of their approach or whether the solution makes sense in its context. With encouragement and self-confidence, they can begin to see math as a contributor to the solution rather than the sticking point.

Finally, presentation of outcomes is given a lot of weight because it is the most-neglected of skills. Unlike an academic exercise, almost every problem in a company has to be handed on to others either for more work or as a solution to be implemented. Its concise and accurate representation is therefore vital if the effort is to be worthwhile.

For the next stage in development of these concepts we are planning five parallel tracks:

1. Carry out a similar math evaluation with other electronics courses in the Department.
2. Dialog with the providers of math service courses to see what they can do to help prepare students for the professional courses that lie ahead.
3. Apply a similar methodology to physics and chemistry.
4. Share the results with Microelectronics students so they can better understand the process and how to prosper within it.
5. Examine the requirements for other major industry groups using the local JACMET training consortium.

References

1. IC Knowledge is a very informative web site with many interlinked technical and economic features. http://www.icknowledge.com

2. The International Technology Roadmap for Semiconductors (ITRS) can be found at: http://public.itrs.net.

3. Robertson, Munukutla and Newman, "Delivery of a common microelectronics technology curriculum at several degree levels", Proc ASEE Annual Conference, Montreal, June 2002.

4. The Arizona Department of Education master list of math skills can be found at: http://partners.is.asu.edu/~techprep/levels/MathRAS.pdf.

Biographical information

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Richard Newman joined ASU in 2001 and is currently Director of Training Operations for the Microelectronics Teaching Factory. In this role, he is responsible for identification, development and delivery of education and training for industry and the other educational sectors in Arizona. He was formerly Associate Director of MATEC (a national center for workforce development) and a faculty member at Arizona Western College.