Measuring and Improving Non-Integrated Engineering Education

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1   Introduction: The American University Ideal of Curriculum Integration

When the modern American University system was being created in the late 1800's (e.g., Harvard, U. Chicago, U. Michigan, Stanford), the goal was to create the unification of the British focus on undergraduate education and the German focus on the research university (Cuban, 1999). These goals were not seen as being in contradiction, but in synergy. The goal was for research to motivate and even inspire better learning and teaching. From the beginning, the education of undergraduates was to be conducted under the direct supervision and advisement of research-driven faculty members.

Larry Cuban's historical analysis of the first 100 years of Stanford University describes how the curriculum altered from this original goal. When Stanford started in the 1890's, each students' four year plan was developed in negotiation with a faculty member, whom the student would select during the freshman year. Departments then, as now, had autonomy over what classes they offered. In individual weekly meetings, faculty members would first help students create a four-year program, and then guide the students through that program. Faculty were available to help explain the program, or individual classes, so that the students could understand how it all was meant to fit together.

However, the one-on-one advising model didn't work out well. From the start, faculty members were driven by their research schedules, and student advisement was often neglected. Administration tried both to force faculty to meet at least one hour a week with each of their student advisees, and to slough off the early undergraduate years to focus on more advanced students (at Stanford, U. Chicago, and U. Michigan). But the Trustees and Regents truly believed in the American University Ideal, so undergraduate education remained a requirement of American Universities.

In 1916, Stanford shifted from the individualized program to a standard curriculum, which required much less advising. The idea of the standardized curriculum was that a set of courses could be selected for students that would make sense and meet the students' general education needs. While Cuban's history shows that Stanford often flirted with a more elective model, the standardized curriculum model won out in all cases (Cuban, 1999).

While the trade-off between an elective curriculum with heavy faculty advisement and a standardized curriculum may seem like a just compromise towards the American University Ideal, the reality is that the standardized curriculum comes at a high cost. Students do not actually understand why they are taking the courses that they are taking (Donald, 1997). Over the last thirty years, higher education students' goals have shifted such that career concerns and financial well-being is more critical than broader philosophical issues (Astin, Green, & Korn, 1987; Williams & Schiralli, 1991), which implies that students goals may be in conflict with the general education goals of standardized curricula (Donald, 1997). Donald has found that one of

the most successful educational reforms in higher education has been to simply increase advising so that students *understand* why they are taking the classes that they are taking.

From a cognitive perspective, we know that it is important for students to see the connections between knowledge areas in order to transfer knowledge between situations (Gick & Holyoak, 1987; King, 1991; Singley & Anderson, 1989). Without seeing these connections, students develop "brittle knowledge" where knowledge is understood only within a given context. Students need to develop more general indices for their knowledge so that appropriate knowledge can be brought to bear in novel situations (Kolodner, 1993).

The first question is whether or not the current standardized curricula work. Do students learn basic skills of mathematics and other domains and then apply them successfully in later studies such as in engineering? The research described in this paper suggests that they do not, that students are unable to use knowledge from previous classes in their problem-solving.

The second question is, if the current curricula don't work, how might they be improved. As Cuban points out, reforming higher education is a very challenging endeavor that runs up against deeply-held beliefs for how Universities are meant to be run. We propose a solution that does not directly challenge existing University structures, but uses technology to facilitate students' getting the information that they need in order to understand their curricula.

In the following section, we describe the experiment we conducted to explore integrative learning in the engineering curriculum of Georgia Tech. We follow with the results of the experiment. We conclude with a section detailing our current project to address these results.

2   Measuring Levels of Integrative Learning

In order to address integrative learning within the engineering curricula at Georgia Institute of Technology (Georgia Tech), we decided to contrast different types of problem contexts and problem calculations. The logic behind this experimental design is that students who are successfully integrating knowledge across disciplines should be able to complete problems of varying context and calculation. If students were successfully integrating knowledge, we would expect them to be able, for example, to solve engineering problems using mathematical tools learned earlier in the curriculum. In particular, we wanted to see if Engineering seniors were able to solve problems in engineering contexts with other kinds of calculations, since non-engineering calculation skills (e.g., calculus, programming) are typically taught much earlier in the curriculum.

2.1   Participants

Thirty-two participants were recruited from Chemical Engineering and Mathematics classes at Georgia Tech. Participants were required to have completed Differential Equations and at least 2 engineering core courses in order to be eligible, and were remunerated with either $10, or extra credit in an introductory psychology course.

Participants were racially diverse, and ranged from Sophomores to Seniors. Half of the participants were chemical engineering majors, with smaller numbers of mechanical engineers, electrical engineers, and various other engineering, mathematics, and science majors making up the difference. Approximately 1/3 of the sample were female (relatively equivalent to the number of women in the engineering program as a whole), and the entire group averaged a GPA of 3.15.

2.2 Materials

We designed a test of 9 problems, which included all iterations of mathematics, chemical engineering, and numerical methods problem contexts and problem calculations. Numerical Methods calculations were represented by the common Engineering modeling language, Matlab, calculations.

CALCULATION:	Mathematics	Chemical Engineering	MATLAB
CONTEXT			
Mathematics	A Math problem requiring a Math solution	A Math problem requiring a solution method common to Chemical Engineering	A Math problem requiring a solution in MATLAB
Chemical Engineering			
Numerical Methods			

Table 1: Test Problems Design with Some Example Descriptions

An example problem that involves a chemical engineering context with a chemical engineering calculation (because of focus on units and need to use the Ideal Gas Law) is:

A hydrogenation reactor requires 154 kmol/hr of hydrogen, the hydrogen costs \$3/1000 ft^3 at standard conditions (T=32F P= 14.7 psia). If the reactor is run for 8000 hours a year calculate the yearly cost of hydrogen for this reactor.

Gas Constant = 8.314 J/mol.K

1 m^3 = 35.3 ft^3

1 atm = 14.7 psi = 101.325 Kpa

An example problem that involves a chemical engineering context and a MATLAB calculation is:

Write a short piece of code that imitates a relief valve. When the pressure, p, is greater than one, the function returns the value 1. When the pressure is less than 0.95 the function returns the value 0. When the pressure is between 0.95 and 1 if the valve was previously 1
return 1 if it's previous position was 0 return 0."

```
        function output_value = valve_position(p)


        %begin{valve_position}
    …
        %end{valve_position}
```

2.3 Procedure

Participants were tested in groups of 2 to 5 individuals in a laboratory room in the School of Psychology. Each participant was seated individually at a desk and asked not to talk or discuss problems with any of the other participants. Once all participants were seated and informed consent was given, the test booklet was passed out, and participants were instructed to work through each problem in order, and not to go back to problems previously worked on. Additionally, participants were asked to note the time they started and completed each problem, as well as to attempt to answer each problem to the best of their ability. Furthermore, if they were for some reason unable to answer the problem, they were instructed to discuss the method

they would have used to solve it, or explain their inability to solve it. Participants were then prompted for questions, and once those were answered, told to begin. Participants were given 2 hours to complete the 9 test problems. If students were still working when the 2 hours were up, the experimenter made the participant aware of the time and collected their exam.

2.4 Results

Test problems were graded on a 5-point scale. If the problem was solved successfully, a score of 5 was given. If the method was correct, but there had been some type of calculation error, a score of 4 was given. Problems solved with generally correct method were given a score of 3. A score of 2 was given when problems used partial correct method, and a score of 1 was given when participants correctly identified variables and successfully completed preliminary calculation work.

Test booklets were graded independently by two graders. There was a high correlation of agreement between the two graders across problems ($r = .83$). These scores were then put into a repeated measures analysis of variance to test for interactions of context and calculation.

If there was integrated learning, we would expect that students would perform similarly within a context despite the calculation, within a calculation despite the context, or similarly over all. But instead, we found significant differences. A significant main effect of calculation was found, $F(2, 62) = 4.49$, $MSE = 7.35$, $p = .02$, where participants scored higher on problems with mathematical calculations over chemical engineering and Matlab calculations. There was a significant interaction of context and calculation, $F(4,124) = 10.58$, $MSE = 21.58$, $p < .01$. This interaction was driven by participants scoring higher on consistent context and calculation problems (e.g., chemical engineering context, chemical engineering calculation) across chemical engineering and numerical methods areas (Table 2).

CALCULATION:	Mathematics	Chemical Engineering	MATLAB
CONTEXT			
Mathematics	2.469	2.500	1.906
Chemical Engineering	2.219	2.906	1.969
Numerical Methods	3.625	1.469	3.00

Table 2: Means for each problem type

	Math	ChemE	NumMethod
ChE Major	2.229	2.375	2.562
ME Major	2.167	2.167	2.556
EE Major	3.222	2.889	3.111
Various Eng	2.143	2.286	2.952

Table 3: Context problem averages, by student major

Neither sex, race, GPA or major, when added as an additional variable, constituted a significant difference. Participants scored higher on problems that were consistent across context and calculation. Surprisingly, matching a major and a context was not a guarantee of

succcess. Electrical Engineering (EE) majors did better on Chemical Engineering context problems than did Chemical Engineers (Table 3)!

Additionally, we examined the length of time it took participants to complete each type of problem as a function of context and calculation. Both a significant main effect of context [$F(2, 62) = 10.81$, MSE = 231.82, $p < .01$] and calculation [$F(2,62) = 25.80$, MSE = 385.02, $p < .01$] were found. In the context main effect, participants took more time to complete mathematics problems, then chemical engineering, spending the least time on numerical methods problems. In the calculation main effect, participants took the most time on chemical engineering calculations over a relatively equal time on mathematics and Matlab calculations.

Finally, there was a significant interaction of context and calculation, $F(4,124) = 9.32$, MSE = 211.22, $p < .01$. This interaction was driven by participants spending more time on mathematics problems overall, but given that students scored higher on mathematics problems, it may be that this extra time was spent in completing the problems they knew how to solve.

2.5 Discussion

The results are somewhat disappointing, though not suprising. In general, students were able to solve problems well when the context and calculation matched well. But where they did not, performance was disappointing. Students' performance in numerical methods is particularly disappointing, considering the importance of these kinds of problems in professional engineering practice. The results suggest that students are not integrating their knowledge across the multiple classes and years of their Engineering curriculum.

There are caveats to these results. It could have been that the mixed context-calculation problems were harder than the same context-calculation problems. However, the consistency of the results suggests otherwise.

3   Improving Integrative Learning

The results of the previous section suggest that Engineering students are not integrating their learning of fundamental calculation methods in early classes (e.g., mathematical and numerical methods) with the contexts learned in their later classes. The most obvious solution is to change curricula so that there are more explicit references between classes and domains. But as Cuban points out, such interactions go against some of the deeply held beliefs about universities, such as autonomous departments who make their own promotion and tenure decisions and who create their own curricula. There are few-to-no rewards for faculty to integrate their classes across departmental boundaries, and it's a very difficult endeavor.

The solution of ABET, the Engineering curriculum accreditation organization, is to use capstone courses in the Senior year to draw together the lessons of the entire curriculum. We have not yet explored the integrative learning between Seniors before and after their capstone courses. However, we doubt that a single course at the very end of the curriculum would play a significant role in integrating students' understanding across four or more years, if there was nothing else going on to encourage integrative understanding across those years.

We are exploring a solution utilizing collaborative learning technologies. We have created a collaborative space (a *CoWeb* for Collaborative Website) which is being used by classes in Chemical Engineering, Mathematics, and Computer Science at the same time, when those classes address the common theme of "computer modeling in MATLAB." There are three goals for the space:

- First, we are creating a resource that students find valuable in solving computational modeling problems in MATLAB, so that they do frequently visit the space.
- Second, we hope that students utilize the space to interact with one another, both across curricular boundaries within the same cohort of students, and across cohorts. We see this interaction occurring within the context of asking for help on homework assignments or questions about computer modeling in Matlab. We hope to see the content of the discussion exploring both the topic, but also about what students do earlier and later in the curriculum.
- Third, we want to see students use the space to recognize connections between classes. Towards this end, we are paying graduate students and advanced undergraduate students to index the space to create connections between pages in different disciplines. For example, we want students visiting a page on a particular kind of differential equation to find a link that shows that this kind of differential equation has a purpose in real problems in Chemical Engineering.

Our exploration of our solution is still just beginning: We are only in our second academic term of use. Nonetheless, log file analysis suggests that we are getting a significant number of visits by students, which may mean that we are meeting our first goal. We are currently creating a handful of explicit collaborations between classes, with faculty willing to work with us, in order to create useful interactions and content for future students to visit.

We are also continuing the kind of surveying and questioning described in the previous section in order to continue to measure the level of integrative learning in Engineering students at Georgia Tech. In particular, we are doing surveys of these sorts in courses on computer modeling in Matlab. As students pass through multiple courses that utilize our webspace, we hope to get additional benefit of students seeing connections and contributing to the webspace to help others.

4   Acknowledgements

5   References

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