What Do I Tell My Students?
(STAO 2008 Conference Notes)

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With
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This session presents results and recommendations from a continuing educational research project examining the student transition from high school to 1st-year university in chemistry. The project started with a pilot project in 2006-7; the majority of the data presented here was collected through an on-line student survey and small group interviews during 2007-8. The key research questions being addressed by this study are:

- What factors contribute to a successful high school–university transition?
- What can schools and universities do to help students manage this transition?

Who are our students?

Some years back, a decision was made to split the 1st-year chemistry program at the U of T St. George campus into two one-semester courses, one of which would be completely devoted to introductory organic chemistry. There were numerous factors involved in making this decision, but one important consideration was that many of the students taking 1st-year chemistry are life science students who also require higher-level biochemistry courses, and these had changed to introduce a significant amount of cell chemistry in 2nd-year. Students can take the courses in either order; the majority take CHM138 in the fall semester, however, as a result of the availability of other common 1st-year courses that are required for life science programs. Chemistry has a separate, year–long course for physical science students that we recommend to any student with a strong interest and academic success in chemistry. Of the ~1800 students enrolled in chemistry in September 2007, 30% participated in the survey. This asked questions about where students went to school, type of program, content covered, and general experience.

Chemical Education Survey:

- Pilot study in 2006-7
- First major survey in 2007-8
- Continuing this year...

What factors contribute to a successful high school–university transition?

What can schools and universities do to help students manage this transition?

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Who Are Our Students?

- 1003 in CHM 138F (Intro. Organic Chem)
- 640 in CHM 139F (Gen. Physical Chem)
- 160 in CHM 151Y (Advanced Intro. Chem)

Survey Response Rate (*n* = 536):	29.7%
Female[3]:	60.6%
Male:	39.4%
Native English-speaker:	44.8%
Semestered Courses:	58.3%
Performed Independent Study Unit:	57.7%

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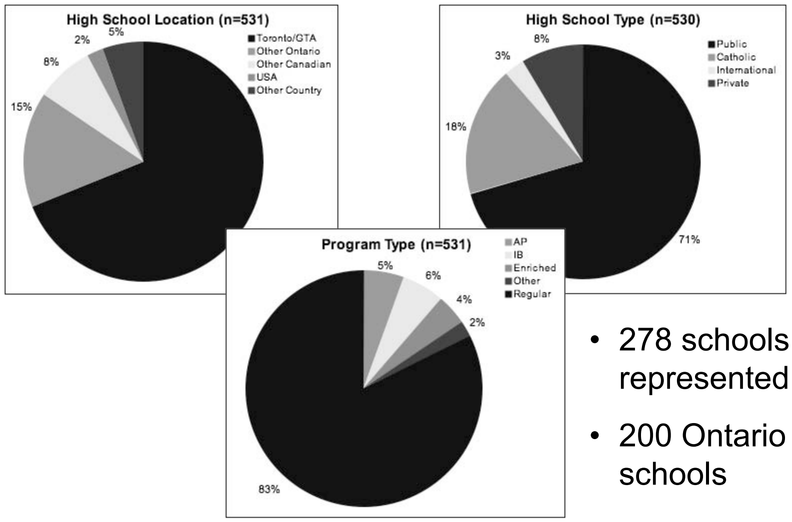
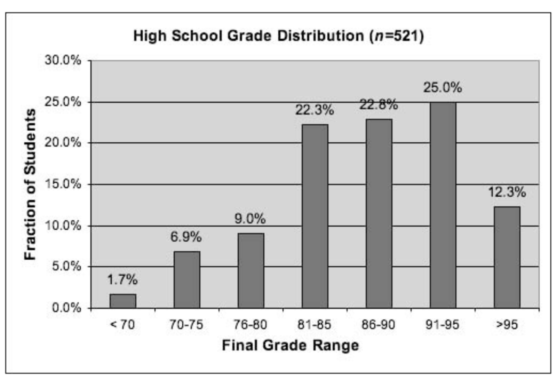
Student Demographics:



- 278 schools represented
- 200 Ontario schools

Student Grade Distributions:



U of T admissions averages in sciences:[1]

- 87.4% (Fall 2005) & 88.5% (Fall 2006)

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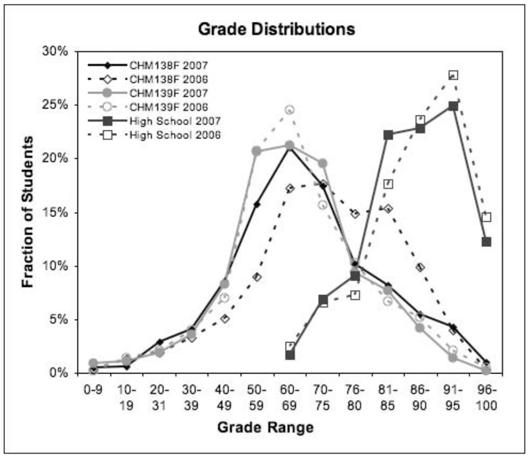
A Grade Disappointment:

Most student comments about the difference between high school and university start with the issue of grades. Many report being told to expect between a 10 and 20 percentage point drop in average grade on attending university. Certainly, the difference between the high school chemistry grade distributions reported by the students, and the class averages for the fall semester 1st-year chemistry courses would appear to support this: the average reported high school grade was around 87%,[1] while the 1st-year course averages typically vary from about 63% to 70%. This suggests a drop of 15-20% is actually typical for our students. For reference, the average university grade on graduation is currently about 71% for the Faculty of Arts & Science (U of T St. George campus). For reference, the marks weighting schemes for the two first year life science chemistry courses are provided, together with an overview of "what a grade means" as far as official grading policy is concerned. It should also be noted that, in accordance with university grading policy, the chemistry department does *not* "grade on a curve" – student final grades are calculated directly from their term work and final exam grades as specified, with *no* manipulation of reported final marks. Two weighting schemes are also applied (see "University Grades") to *every* student's grades; the higher mark as calculated from each scheme is the one recorded as the student's final course grade.

Grades – Winners and Losers:

One of the recurring comments about grades is that many students did not perform anywhere near as well as they expected, even allowing for the overall drop in course average between high school and university. (See "Student Voices – Grades" for selected examples.) To examine this aspect in more detail, a grade differential was calculated for all students in the survey cohort for whom we had course grades, and who had written the final exam in the relevant course. (Not all students write the final for various reasons; these would obviously skew the data.) A negative grade differential (*GD*) indicates a drop in grade relative to high school chemistry, while a positive *GD* indicates an increase. The average *GD* is, indeed, around –16% but the spread is equally large, with a standard deviation of ±15%. This means that 63% of students can expect to achieve a grade that is anywhere from equivalent to their high school grade, to up to 30 percentage points lower! A similar result is observed for students from AP and IB programs.[2] Looked at another way, the distribution of grade differentials means that while 25% of students may actually improve their chemistry course grade, 25% will drop between 25 and 55% in grade.

A Grade Disappointment:



High School:
- 87% (2006)
- 87% (2007)

CHM 138F (Organic):
- 69.7% (2006)
- 65.0% (2007)

CHM 139F (Physical):
- 63.8% (2006)
- 63.3% (2007)

University Grades:

Marking schemes for CHM138 & CHM139:

Course Component	Primary	Alternate
Tutorial quizzes *etc.* (3/4 or 5/6):	5%	5%
Term tests (2):	40%	25%
Lab component (5 labs):	20%	20%
Final exam:	35%	50%
Instructional days:	56 (39 lectures)	

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What's in an A?

Grade	Range	Expectation[2]
A	80-100	Original thinking; analysis & synthesis; organization; critical evaluation; extensive knowledge
B	70-79	Grasp of subject; critical capacity; understanding of issues; familiarity with literature
C	60-69	Profiting from university experience; develops solutions to simple problems

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Student Voices - Grades:

"Even though most of us expected that University Chemistry is going to be challenging, I think that a lot of people believed that because they did well in high school, it automatically translate into doing well in university as well, which may not be the case at all."

"I find university chemistry to be extremely difficult. Although I still love chemistry, I am close to failing and that makes me excruciatingly sad."

"Overall, I was very lucky. My teacher taught us how to learn chemistry and always discouraged memorizing concepts. As a matter of fact, I've been told that most people achieve higher marks in CHM 138/139 than in his class."

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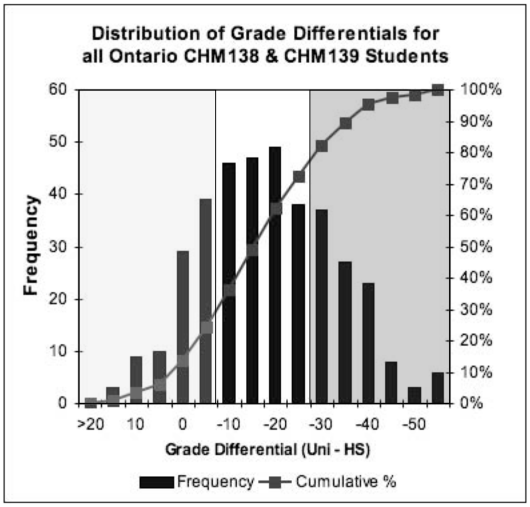
Winners and Losers:



- GD = Uni – HS
- Mean GD for all students is –16.4 (n = 374, s = 14.5)
- Mean GD for AP/IB students only is –15.9 (n = 31, s = 13.5)

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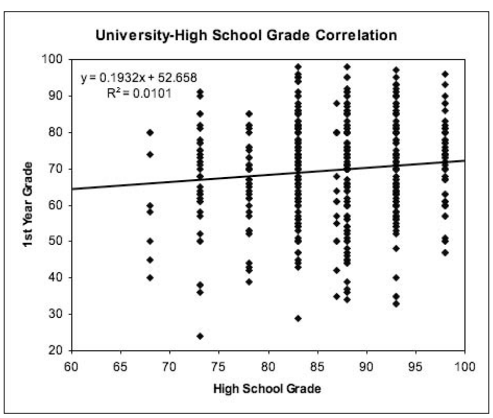
A Grade Disappointment (2):



- High school grades assigned as central value for each range
- Missing high school grades imputed from average
- Only students who wrote 1st-year final exam
- **<u>No</u>** correlation at the 99% confidence level!
- **<u>No</u>** difference between CHM138 & CHM139!

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A Grade Disappointment (2):

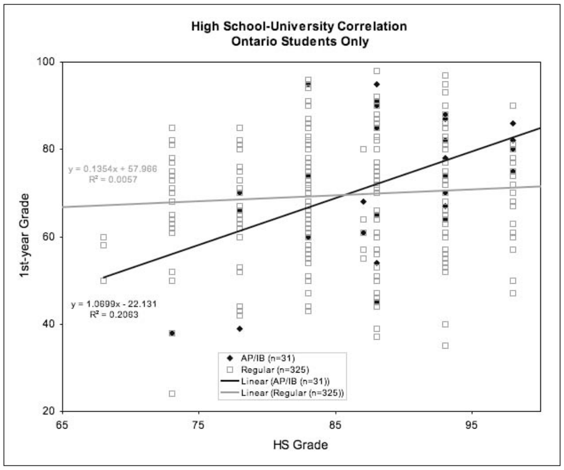
Another way to look at student grades is to identify any correlation that may exist between high school and university grades (see "A Grade Disappointment (2)"); essentially, there is *no* correlation observable, even if the data is restricted only to Ontario students (who share the same minimum curriculum requirements). Neither is there any difference (*i.e.* no correlation continues is observed) if the data is further refined to look at CHM138 (organic) and CHM139 (physical chemistry) separately; this was somewhat surprising, since the CHM139 curriculum provides – at least on paper – much greater overlap with the Ontario grade 12 chemistry curriculum. There is a correlation for AP and IB students combined which is *just* significant at the 99% confidence level; current project students have looked in more detail at the data, but have found no sign of any affect from gender, median family income, or other suspected predictors. There are insufficient numbers of participants within the survey cohort to examine any potential influence of a student's particular high school.

It is interesting to note the similarities and differences between this study and a recently published US survey.[3] The authors of this study looked at first year students across a variety of academic institutions, and found that their regression model "accounted for 38.2%" of the variance in 1st-year college/university chemistry grades, based on a final sample size of 1333 (out of 1531) surveys. The top predictors of 1st-year college or university chemistry grade are shown; it is noteworthy that *any* effects due to ethnic background could be eliminated by taking into account factors such as level of parental education and availability of AP high school courses. Given the centrality of stoichiometry to all aspects of the high school chemistry curriculum, as well as the importance of math skills, it is perhaps not surprising that this is the one chemistry topic that seems to have any bearing on 1st-year university or college chemistry grade.

Student Perceptions:

A number of the survey questions related to the student high school experience. Some of these questions were drawn from the US study in an attempt to see how high school study habits relate to university success. It is interesting to see that students are split 1/3rd in finding high school challenging, and 1/3rd reporting that it wasn't challenging enough. Student comments on the survey and in group interviews frequently express the view that their high school course *should* have become more challenging towards the end, in order to better prepare them for the demands of university. Most students obviously expect to do well,

AP/IB Student Advantage?



- Ontario only
- Regular stream (green, *n*=325)
- AP (16) & IB (15) combined (blue)
- **No** correlation for regular stream
- Slight correlation for AP/IB
- **No** correlation for enriched/gifted

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Correlation Results:

Course	*n*	*r*	*t*	*p*
Both	478	0.100	2.193	0.029
CHM138F	333	0.098	1.801	0.073
CHM139F	145	0.087	1.046	0.297
Regular	326	0.075	1.363	0.174
AP/IB	31	0.454	2.745	0.010
Enriched	18	-0.288	1.204	0.246

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Top Grade Predictors:

1. Last HS Math Grade (AP and/or calculus) – SAT Math score also highly significant
2. Last HS science grade (not specifically chemistry)
3. Time spent on stoichiometry (*recurring topic*)
4. AP instead of regular chemistry; emphasis on understanding *vs.* memorization

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Student Perceptions - School:

1. Labs were useful and relevant to topics
2. I found HS chemistry challenging
3. I expect to do well in university chemistry
4. I always completed my homework
5. I learnt much independently
6. I procrastinated over my homework
7. My HS teacher performed effectively
8. HS placed more emphasis on memorization

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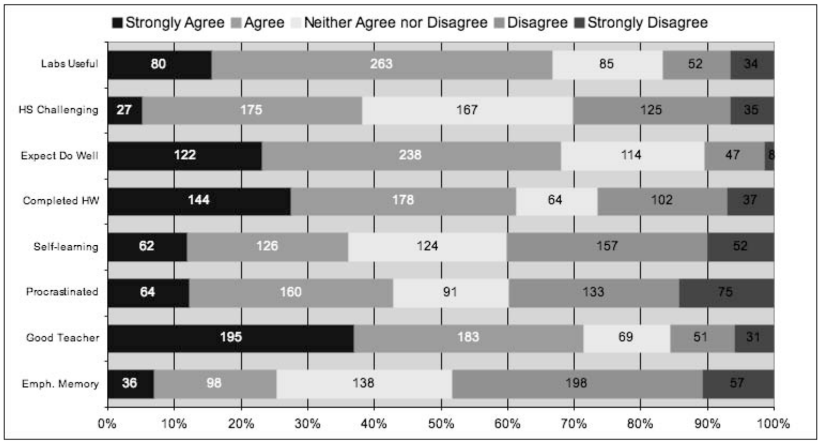
Student Perceptions - School:



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Topical Content:

- Nuclear Chemistry (isotopes, radio decay, *etc.*)
- Biochemistry (enzymes, proteins, DNA/RNA)
- Forces & Bonding (VSEPR. van der Waal's, *etc.*)
- Electrochemistry (redox, galvanic & voltaic cells)
- Thermochemistry & Kinetics (Hess' Law, *etc.*)
- Organic Chemistry (naming, groups, reactions)
- Gases (properties, gas laws)
- Equilibria (reactions, acid/base, solubility)
- Stoichiometry (chemical reactions & equations)
- The Periodic Table (electron config., periodicity)

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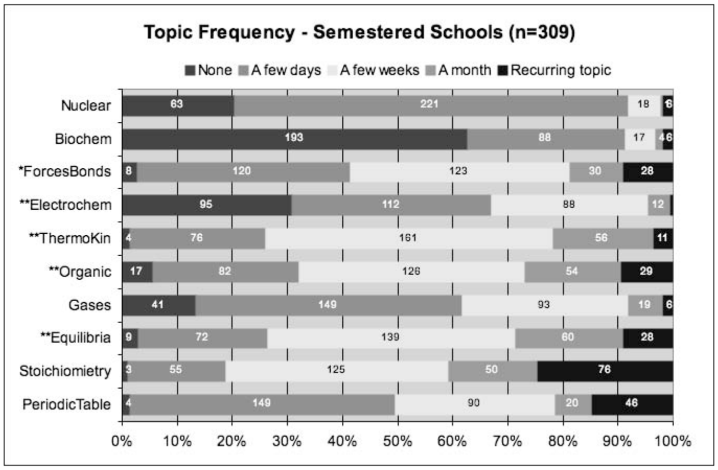
especially given their high school grades. As noted earlier, however, this is a source of major disappointment for a significant proportion of students: comments along the lines of university being the place where "hopes and dreams come to be crushed" are not uncommon. The vast majority of students also felt that their high school teachers did a good job overall, but those who had a negative opinion were often extremely critical of their teacher's behaviour and performance. One suspects that this minority of teachers are highly unlikely to be attending STAO, however, so no more will be said on this subject! So far, there is insufficient data to determine the level to which habits such as procrastination, self-directed study, and homework completion relate to success in 1st-year.

Perhaps one of the more contentious findings is the 25% of students who felt that high school was more about memorization than understanding. This number is consistent with the 2006-7 pilot survey, and is also a common theme emerging from student comments and interviews. Typically, this is expressed as "all I had to do was memorize stuff the night before a test or exam, and I got an A". One thought about this is that it may be more to do with the nature of the assessment questions than the nature of the teaching: in the currently running survey, this question has therefore been split in an attempt to gain further insight. It is worth noting, however, the consistent finding by Prof. Lori Jones at the University of Guelph[4] that students correctly identify the geometry of a water molecule as "bent", but almost universally fail to identify the same geometry when described in terms of the number of atoms, bonds, and lone pairs…

Topical Content:

The US study mentioned previously examined the importance of "time on topic" by breaking down the curriculum into common subject themes. The current survey used the same topical headings for consistency, although these are not a good fit with the current Ontario curriculum. Other problems with this type of question are (1) the frequency of classes, and therefore time period spent on a specific topic, will vary between semester and year courses, and (2) the question really assesses student recall and perception of the time spent on the various topics. With that in mind, the survey data for semester and year–long programs are presented separately. Similar trends are observed between the two, however. It is reassuring to find that many students recognize stoichiometry as a recurring topic! Most notable is the *lack* of time spent on electrochemistry, which is one of the areas students struggle with most in 1st-year, yet is probably one of the most important to understand both from a biochemical and alternate ('green') energy point of view. A lack of *quality* time spent on organic is also a recurring theme of

Topical Content - Semestered



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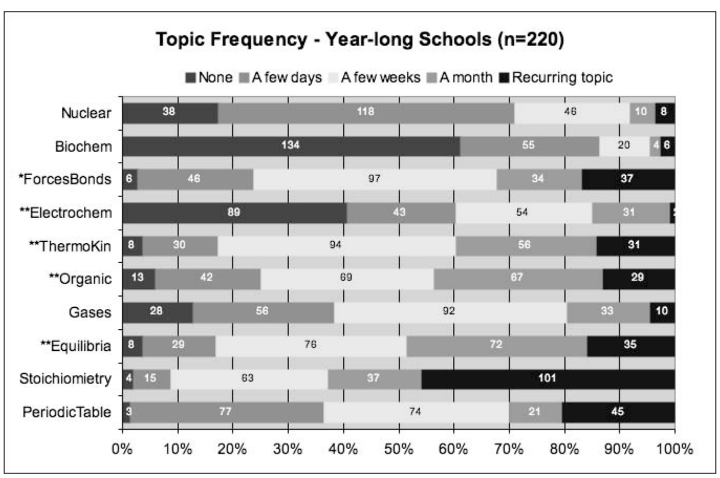
Topical Content - Year-long



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student comments and interviews, especially given the fact that the majority of the survey participants were taking organic chemistry at the time the survey was run. Finaly, students struggle with in general/physical chemistry is thermochemistry and thermodynamics: Hess' law and specific heat calculations are fine, but students struggle to correctly identify state functions and, as a consequence, frequently have a very hard time with entropy when it is introduced.

Focus Group Themes:

Only a relatively small number of students attended focus group sessions, but insights can still be obtained from these interviews. Data was analysed from five separate interviews, comprising a total of 24 students. These were supplemented with comments from the actual surveys for additional information. The transcripts and comments were analysed for recurring topics or themes, with individual student responses being coded as negative, neutral, or positive on each theme. We will look at the five main themes in turn.

Teaching: not surprisingly, many of the comments centred on teaching practices. One of the questions used in the interviews asked what high school teachers had done by way of preparing students for university-style classes. Representative student quotes are included (see slide). Clearly, some teachers adopted a lecture approach, but not always according to best practices! In fact, the lecture is probably the worst way to teach, but is pretty much a fact of life given the large class sizes associated with 1st-year chemistry in most Ontario universities.[5] Student performance in lectures has been studied fairly extensively.[6] In essence, the key findings are that:

- Skeletal handouts are better than bare slides, complete notes, or "fill in the blank" sheets; ideally, these should provide a framework for student notes, with key diagrams and equations included in order to avoid transcription errors
- It is essential that students should learn how to take actual *notes*, rather than dictation! Reading *ahead* of the lecture is essential, particularly when dealing with new material
- Students who elaborate on their notes within 24-48 hours score much higher on both immediate and long-term recall and conceptual tests

These are all things that can be emphasized at the high school level, and can potentially be incorporated as an assessment component since proper and effective note taking is an essential communication skill! One way to achieve this is to have

Focus Group Themes:

- Teaching & evaluation practices
- Use of text (by student or teacher)
- Self-directed learning & pace of material
- Relevance & complexity of labs
- Organic coverage from curriculum

Student Voices – Teaching:

"We kinda had to teach ourselves … [the teacher] would put [overheads] on the board and as we were trying to copy them down, [they] would explain so no one would actually listen to her."

"My teacher … taught very much like a professor … he gave us notes ahead of time [and] would assign readings ahead of time. … It's just that I find university a lot more fast paced…"

"I find that I'm doing better than I [did] in high school, but the only reasons why is because I was scared… I'm actually glad that the teachers took the time to tell us about their past experience in university…"

"My Physics teacher … taught a lot about what to expect … strategies and attitudes we'd have to have."

A Lousy Way to Learn!

- The average 50 minute lecture contains:
  - 4850 spoken words
  - 560 written words
  - 130 discrete units of information

- The average student records:
  - 97% of written words
  - 56% of total information

(Source: Johnstone & Su, Education in Chemistry, 1994, 81(3), 75-79)

Note-Taking Style Outcomes:

Note-taking style	1st Exam (Jan)	2nd Exam (Apr)
Board signals (incomplete)	29.3%	32.0%
Board signals only	43.0%	49.7%
Board + extra	56.8%	65.5%
Elaborated notes	75.0%	79.0%

students submit their notes (possibly after allowing time for elaboration) as an assignment. Some flexibility in grading is required, depending on note-taking style, but essentially students should receive feedback on accuracy, completeness, and amount of elaboration. Aside from this, one of the most important things teachers can do is recount their *own* experiences of university, particularly with regard to lectures, note taking, and the pace of learning.

Evaluation Practices: Another source of student frustration inevitably involves differences in evaluation practices between high school and university. The three main concerns are (a) the extensive use of multiple choice questions in university, (b) the emphasis on concepts and problem-solving, and (c) a perception that university instructors ask questions on material not covered in class.

Some students report being very concerned about multiple choice questions, and even express the feeling that their high school teacher should have made more extensive use of such questions to prepare them for university. This was at first surprising, but it appears the main point of concern is with conceptual, rather than calculation or recall, questions. An example is included here; note that instructors do not always word these as well – options that include "All of the above are true" and "None of the above are true" are often problematic. A problem encountered by university instructors is that many textbook end-of-chapter questions are in fact simple recall or calculation exercises, and do not really test conceptual understanding. As such, students frequently make false assumptions about the nature of questions on tests and exams even when given explicit instructions to concentrate on conceptual questions!

Students are also generally very poor at actual *problem-solving*, or applied learning, questions (see examples.) The same comment has been made by colleagues in the physics department, which has experienced a significant drop–out rate amongst first-year life science students. Generally, students are very able to answer recall ("Define momentum") and simple calculation ("Calculate the momentum of a 150 g mass moving with a velocity of 25 m/s"), but do not connect these basics with concepts or see how to apply them to real life ("How much force would a hockey face-shield have to withstand in order to protect the player from a direct hit by a hockey puck?") With regard to the chemistry examples shown, the first question refers to an illustration and section of material in the text, connected with later material on heat capacity; the second is simply a variation on the frequent discussion of phase diagrams in terms of how we can skate on ice, but not on other materials. It is therefore *not* the case that we are asking students questions on material they have not seen before; rather, it appears that many students either

Student Voices – Evaluation:

"My biology teacher … took a university exam and structured his questions on those questions"

"I think the multiple choice was something that I was really worried about."

"In high school, the [tests] were more memorizational and less conceptually based (i.e. one could get an A without knowing chemistry"

"They [university] test your ability to take tests"

"Questions on high school tests involving higher thinking are rare."

"In AP they gave us more application questions and its basically what they are giving us now."

Multiple Choice - Conceptual

Consider the following statements about a liquid in dynamic equilibrium with its vapour at a specified temperature:

1. There is no transfer of molecules between liquid and vapour
2. The vapour pressure has a unique value
3. The opposing processes proceed at equal rates
4. The concentration of vapour is dependent on time

Of these statements:

a) Only (1) is correct
b) Only (2) and (3) are correct
c) Only (1), (2) and (3) are correct
d) Only (2) and (4) are correct
e) None of the statements are correct

Problem Solving/Application:

1. The Horseshoe Falls are 49 m high. Assuming all the potential energy of the water is converted to heat, how much warmer is the water at the bottom of the falls than at the top?

2. With reference to the phase diagram for water (provided), why is it possible for lakes to exist in Antartica under 40 km of ice, even when the temperature drops to –90 °C?

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Applied Learning (Extreme!):

One of the most important reactions occurring on the planet is the reduction of N_2 to form nitrogen based biopolymers such as DNA and proteins. Nitrogen in the atmosphere is only very slowly reduced to ammonia with external sources of energy such as lightning strikes. The enzyme nitrogenase is quite unique in that it is able to break one of the strongest bonds known – the nitrogen triple bond. The key step appears to involve binding of N_2 to a Mo atom in the protein complex. Your task is to design a hybrid catalyst to produce ammonia from N_2 using myoglobin – the oxygen transport protein in muscle – as a template. Myoglobin already has the capability to bind small molecules such as O_2 to an iron atom, which is easily substituted with Mo. Your challenge is to use either chemical modification or genetic engineering to modify myoglobin to produce a new super catalyst for N_2 reduction…

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Applied Learning (Extreme!):

1. The Mo binding site will only partially lower the N_2 triple bond energy. You need to modify the protein to place an electron withdrawing group at the unbound end of the N_2 molecule to further weaken the bond. Draw the reaction coordinate showing the effect of your modification on your protein, before and after protein engineering. Offer a brief description of catalysis and discuss it in the context of your activation energy diagram.

Student Voices – Pace:

"[The pace at university] is quite a lot faster, and it requires a lot of motivation on your part and independent learning"

"There's always pressure being put on you"

"I found that my time management skills were the only thing that was keeping me alive."

"There's four other mid-terms [in other courses] between the first and second midterm and like I didn't even go to any chemistry lectures and by the second mid-term two days before that…"

"I think it would have been better if, like, at the end of high school , they cranked it up a bit"

have a very weak conceptual understanding or lack training in problem-solving strategies, making it hard to relate the question to what know.

This is particularly evident with the final example, which I would consider an extreme (and extremely rare) example of this type of problem! As you can see, there is a great deal of text to wade through before coming to the actual question. Many students taking this exam probably gave up long before the actual question, having (wrongly) concluded that the question would be impossible. In fact, it is a simple enzyme kinetics question, which had actually been discussed in lectures! The vast majority of students, however, did not write anything for this question.

Other Themes: After teaching and evaluation practices, the most common themes related to the fast pace and self-directed nature of university learning. Students frequently admitted that they did not keep up with the lecture material and homework assignments, resulting on a poor performance on the first test. Unfortunately, it is extremely difficult to catch up once behind. A confounding factor here, particularly for the general chemistry course, is that the material frequently *looks* familiar to students, so they don't bother to work through problems and assignments. It is then only on the test that they discover the extent to which they are either unfamiliar with, or have learned incorrectly, the course material. Perhaps the single biggest mistake in this regard is, when confronted by a difficult problem, to look up the solution and simply say, "Oh yes, I know that!" *without* going back and working through the problem independently. Our recommendation is to participate in study groups, within which you have to explain or justify why your solution is correct; certainly, educational research shows that such peer–learning is much more effective over the long term than many other forms of instruction.

Students also find themselves unprepared for the length and complexity of labs (typically 3 hours in first year) and ill-prepared for writing lab reports. Most large university chemistry courses provide students with streamlined forms to fill out and submit, rather than having them write formal lab reports. This is simply because it is impossible to read and grade the many hundreds of reports that would result. One are where students struggle is in presenting their calculations in a clear and concise fashion. Take, for example, a simple titration calculation. Students tend to make two mistakes: either they use the dilution equation to calculate the end-point ($C_1V_1 = C_2V_2$) – presumably because they rarely encounter titrations with stoichiometry other than 1:1 in practice – or they perform convoluted calculations in which everything is converted from concentration to moles and then back again. The latter not only makes it difficult for a marker to follow what has been done (often because the calculation is not annotated), but requires the student to perform significantly more calculations, especially when performing error propagation.

The final theme relates to organic chemistry. When covered, many students state that all they did was nomenclature, with very little work on reactions. Many students also report that organic was not formally taught in class, but assigned as an independent study unit and not necessarily graded. Finally, a number commented that organic was taught mainly as an exercise in memorization, with very little emphasis on the concepts underlying why reactions work they way they do. As far as nomenclature is concerned, it should be noted that very little time is spent on this in university. In fact, software packages exist that are considerably better (and more accurate) in naming compounds from their structure[7] than the researchers who synthesize the compounds are! Such packages are also excellent in terms of helping students learn to visualise the structure of molecules in space as 3D objects,[8] which is probably one of the most crucial skills for understanding organic reactions. Many illustrations and animations are also available *via* the internet, and can be a useful source of instructional materials.

Closing Thoughts:

The overriding conclusion from the research project is that high school grades are very poor predictors of university performance, yet many students assume the opposite. The US study cited earlier provides a summary of earlier studies on the relationship between high school and college/university grades with the following quote from a 1976 review paper:[9]

> "There is some indication that taking high school chemistry may be used as an indicator of success in college chemistry ... There is also evidence that no indicator is all that good."

It is disappointing to learn that, after more than 30 years of research and reform, this is still true today.

So how can teachers prepare their students for university (and not just for chemistry)? Perhaps we can take a cue from the retrospective views of recent high school graduates, and there evaluation of those practices on the part of their high school teachers that most prepared them for university. These include:

- Emphasizing good note-taking skills
- Emphasizing the habit of reading ahead, and reviewing after, each class

- Emphasizing *effective* study habits and skills, particularly short but frequent study sessions
- Teaching true problem-solving skills and strategies, particularly what to do when stuck![10]
- Using appropriate visualization tools (models and software) in organic chemistry

What about curriculum content and depth of conceptual understanding? While recognizing the difficulty of covering the full extent of the grade 12 curriculum, it is certainly possible to provide students with opportunities to compare their progress relative to what might be expected at a university level. The Canadian Chemistry Contest (CCC), for example, provides both multiple choice and written questions covering the key content of the Pan-Canadian Protocol (on which the Ontario curriculum is partly based.) While the timing of the actual competition is not always convenient – especially for students in semestered programs – the web site for the contest provides valuable resources for teachers.[11] This includes not only past years' exams, but solutions and notes, indicating areas of difficulty and likely reasons for that. Generally, I would expect students who have completed the grade 12 chemistry curriculum and score better than 18/25 to be reasonably confident of doing well in our 1st-year courses. A second resource is the Canadian Chemistry Olympiad (CCO).[12] Again, this will probably not be an attractive contest for many students, in part because the International Chemistry Olympiad effectively functions at a level equivalent to Canadian 1st-year undergraduate studies.[13] As with the CCC, however, the on-line preparatory problem sets posted each year provide a valuable resource for more advanced questions, which can be used to challenge better students and keep them interested. The host country for the international competition also provides preparatory problem sets and solutions, many of which could be adapted as problem-solving exercises.

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Note: *If you have any questions or comments, or would like further information about any aspect of this presentation, please feel free to contact Dr. Stone – dstone@chem.utoronto.ca*

Footnotes:

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[1] I am frequently asked if the students aren't simply inflating or misremembering their high school grades. This is unlikely for several reasons: first, the average is close to the reported average for admissions purposes (based on English, 2 math, and the top 3 grades in any other subjects); second, student recall is good when provided with cues; third, entry to U of T is highly competitive, and these students usually have a very good idea of their grades; fourth, students have no reason to inflate their reported grades.

[2] The number of students from AP and IB programs participating in the survey is artificially low as those who obtain a grade of 4 or higher (AP) or 5 and above (IB) can receive credit for CHM139. Some waive the credit in order to have an easier 1st-year and obtain a higher grade for program selection purposes. Many of those who accept the credit and jump straight into 2nd-year chemistry courses struggle with the material, as they have not yet adjusted to the university pace and academic environment.

[3] R. H. Tai, P. M. Sadler, and J. F. Loehr, *J. Res. Sci. Teaching*, **2005**, *42(9)*, 987-1012; R. H. Tai, R. B. Ward, and P. M. Sadler, *J. Chem. Ed.*, **2006**, *83(11)*, 1703-1711; R. H. Tai and P. M. Sadler, *J. Chem. Ed*., **2007**, *84(6)*, 1040-1046.

[4] Lori Jones, "Surviving Killer Chem", STAO presentations in 2007, 2008 and 2009.

[5] At the St. George campus, 1st-year chemistry lecture sections are capped at about 400 students; class sizes in other subjects can be up 900 or more students, although only 12 courses fall into this size category.

[6] Johnstone & Su, *Education in Chemistry*, **1994**, *81(3),* 75-79.

[7] ACD/Labs ChemSketch™ (http://www.acdlabs.com/download/chemsk.html) with the ACD/Name Freeware Add-on (http://www.acdlabs.com/products/name_lab/name/)

[8] JMol (http://jmol.sourceforge.net/), a Java-based 3D molecular viewer

[9] W. R. Ogden, *School Science & Mathematics*, **1976**, *76*, 122-126.

[10] Studies have shown that students will persist in unproductive problem-solving strategies unless they are redirected, or learn how to recognise such behaviour and self-redirect

[11] http://www.chemistry.ca/nhsce

[12] http://www.chem.utoronto.ca/IChO.Ontario/

[13] Students who attend the National Olympiad Finals, or go on to represent Canada in the international competition, often receive a waiver for 1st-year university chemistry courses.