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ABSTRACT

Increases in attrition rates among science, mathematics, and engineering (SME) majors have produced a variety of deleterious effects for society. This paper attempts to clarify and interpret the interaction of those characteristics of the structure and culture of undergraduate SME programs that perpetuate high loss rates among their first-year college majors by looking at a number of studies of SME programs and undergraduate attrition. The interaction of instructional factors, differing high school and faculty expectations for entering SME undergraduates, and epistemological considerations was found to contribute to a higher dissatisfaction among SME majors as compared with non-SME major and to resulting student attrition. Significant support was not seen for the contribution of commonly cited explanations of SME attrition such as cognitive factors and large class sizes. (Contains 19 references.) (Author/SLD)

AN ANALYSIS OF THE HIGH ATTRITION RATES AMONG FIRST YEAR COLLEGE SCIENCE, MATH AND ENGINEERING MAJORS

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ABSTRACT

Increases in attrition rates among science, mathematics, and engineering (SME) majors have produced a variety of deleterious effects for the society. This paper attempts to clarify and interpret the interaction of those characteristics of the structure and culture of undergraduate SME programs that perpetuate high loss rates among their first year college majors. The interaction of instructional factors, differing high school and college faculty expectations for entering SME undergraduates, and epistemological considerations was found to contribute to a higher dissatisfaction among SME majors as compared with non-SME majors and the resulting attrition. Significant support was not seen for the contribution of commonly cited explanations of SME attrition such as cognitive factors and large class sizes.

INTRODUCTION

Too few undergraduates are recruited and retained in science programs to meet the nation's future needs (Seymour & Hewitt, 1997). The National Research Council (1996) points out a 25 year decline in first-year student interest in choosing majors in undergraduate science. First-year student interest in undergraduate science majors declined from 11.5% in 1966 to 5.8% in 1988. The largest declines were seen in mathematics (from 4.6% to 0.6%) and the physical sciences (3.3% to 1.5%) (Seymour & Hewitt, 1997).

U.S. census data also show that potential majors in science, math, and engineering (SME) are lost particularly in the transition from high school to college by freshmen switching from SME majors to non-SME majors (Seymour & Hewitt, 1997). Astin and Astin (1993) indicated that a student loss rate of 40% occurs at this juncture (between high school and the first-year of college) from SME majors on the whole, with losses ranging from 50% in the biological sciences to 20% in the physical sciences and mathematics.

The greatest losses of students were found among high school graduates who withdrew their decisions to enter an SME major at or before enrollment in college (Astin & Astin, 1993). However, during college, the highest risk of SME switching (35%) occurred at the end of the first year (Seymour & Hewitt, 1997). As student time in college increases, risk of attrition declines, with Hilton and Lee (1988) reporting a loss between sophomore and junior year of only 2% and from the start of the junior year to graduation, .8%. Interestingly, however, very few students transfer into SME majors after college enrollment and there is always a net loss (Hilton & Lee, 1988). Green (1989) thus pointed out that "not only do the sciences have the highest defection rates of any undergraduate major, they also have the lowest rates of recruitment from any other major" (p.478).

Career entry in SME areas has obviously been affected by these attrition rates, whereby both the health professions and engineering areas have lost over half of their entrants in the past decade (53% and 51%, respectively) (Seymour & Hewitt, 1997). Particularly, a shortage in the supply of science teachers in various geographic areas has been noted by the National Research Council (1996). Considering the rise in college enrollment, the reported declines of 60% in the number of students preparing to teach science is alarming . (National Research Council, 1996; Champagne & Hornig, 1985). Although a variety of factors have purportedly contributed to this situation of SME teacher scarcity, clearly the high attrition rates for SME majors have played a role, according to Champagne and Hornig (1985).

The ramifications of this decrease in SME enrollment are evidenced in the studies showing a declining scientific literacy of the population as a whole (Seymour & Hewitt, 1997). This has produced a nation that has "simultaneously and paradoxically both the best scientists and the most scientifically illiterate young people..." (Goodstein, 1993, p. 108).

This declining scientific literacy, combined with the decreases in SME enrollment, has resulted in reduced numbers of qualified individuals available for not only science teaching but also research development, a driving force in the progress of science. Public concern has thus been expressed regarding U.S. international competitiveness in the science and technology-dependent sectors of the economy (Seymour & Hewitt, 1997).

Although serious deficiencies in SME education have been recognized by the scientific community, attempts should be made to improve student retention and achievement among college SME majors (McShannon, 2001). Thus, a major purpose of this paper is to explore the empirical evidence explaining the increasing rates of attrition in SME areas with the hope of ameliorating the deleterious effects of the current educational system on the future of scientific development.

ANALYSIS OF THE RESEARCH

University faculty have traditionally explained undergraduate attrition from SME majors as appropriate, claiming that the unprepared and lazy are weeded out (Seymour & Hewitt, 1994). However, these notions about the nature of undergraduate science are not based on systematic exploration (Seymour & Hewitt, 1997). A variety of studies have been conducted in order to tease out the variables that contribute to a student's decision to switch from an SME major (e.g. Loftin, 1993; Razali & Yager, 1994; Strenta, Elliott, Adair, Matier, and Scott, 1994; Seymour & Hewitt, 1997; Daempfle, 2000; McShannon, 2001).

instruction and the "chilly climate hypothesis"

The overall aim of an extensive study by Seymour and Hewitt (1994) was to establish the relative importance of factors influencing the decisions of undergraduates to switch from SME majors to non-science based disciplines. Seymour and Hewitt (1994) conducted an ethnographic study over a three-year period (1990-93) with 335 students in SME majors drawn from seven university campuses that contained a high proportion of these majors. Most of the data were gathered by personal interview. An additional 125 other students participated in focus groups on six other campuses (Seymour & Hewitt, 1994).

In order to hold the variable of academic ability constant in explaining attrition, Seymour and Hewitt (1994) studied only students who were considered well prepared for college SME majors, having math SAT scores above 649. Half of the students included those switching from SME majors and the other half included the "persisters" (those remaining in the SME majors) (Seymour & Hewitt, 1994).

Seymour and Hewitt (1994) reported the same set of concerns described by both groups as leading to switching and serious discontentment among persisters. A set of 23 concerns was shared by switchers and non-switchers alike. Nine out of ten switchers and three out of four persisters described the quality of science instruction as poor overall. Concerns about pedagogical effectiveness, assessment factors, and curricular structure appeared in all issues raised. The results showed that students strongly believed that faculty did not like to teach, did not value teaching as a professional activity, and valued their research above teaching (Seymour & Hewitt, 1994).

When asked to compare SME courses with non-SME courses, students expressed strong contrasts: coldness vs. warmth; elitism vs. democracy; aloofness vs. openness; and rejection vs. support. The most common words used by first-year students to describe their personal encounters with SME faculty were "unapproachable", "cold", "unavailable". "aloof", "indifferent", and "intimidating". Students further elaborated, according to results by Seymour and Hewitt (1994), describing the coldness of an SME classroom as based on sarcasm and ridicule by faculty. These practices, rarely found in non-SME courses, are described by students as discouraging voluntary student participation and creating an atmosphere of intimidation that switchers cited as a main cause of their decision to leave their SME major (Seymour & Hewitt, 1994). Attribution of this type of classroom structure to attrition is termed in the literature, "the chilly climate hypothesis".

Criticism by students also focused on a lack of discussion in the college classroom, with only one-way lectures, according to Seymour and Hewitt's (1994) study. Interestingly, students valued their high school experiences, which they described as containing much dialogue, over their college lecture courses in SME areas. Poor preparation, a focus on rote memory, and faculty reading directly from textbooks were described as contributing to poor SME instruction (Seymour & Hewitt, 1994).

Although a common explanation by science faculty for the high attrition rates in SME is poor high school preparation, students in both Seymour and Hewitt's (1994) and Strenta, Elliott, Adair, Matier, and Scott's (1994) studies appear to value their high school experiences in science and math over the college SME courses, citing more interesting and better instruction. This does not negate the opinions of faculty, but indicates a difference in expectations of high school and college faculty for their students and a favoring of the high school situation by students. Analysis of reasons for preference for high school instruction was limited to the student interviews expressing displeasure with the chilly climate of college vs. the nuturing environment of their high schools.

In an extension of the research on attrition due to instructional criticisms in undergraduate SME areas, Strenta et al. (1994) used much larger sample sizes as compared with Seymour and Hewitt (1994) to discover some of the causes of initial interest in and attrition from natural science and engineering as compared with non-science areas (N=5320) in four highly selective institutions. Again, holding academic performance variables constant among persisters and non-persisters, these students were similar to those studied by Seymour and Hewitt (1994), with average combined SAT scores of 1310 and high school grades at the 95th percentile. However, the results found by Seymour and Hewitt (1994, 1997) do not compare the views of SME majors with those of non-SME majors as seen in Strenta et al.'s (1994) study.

Strenta's et al. (1994) findings were obtained through an extensive ethnographic study and support the notion that instructional criticisms are greater among SME majors as compared with non-SME majors. The results show strong area effects, with students viewing science classes as relatively unwelcoming and competitive. Students cite instructor sarcasm and curving procedures as primary contributors such an atmosphere, thus supporting Seymour and Hewitt's (1994, 1997) chilly climate hypothesis for attrition in SME areas. The basic sciences were all considered duller than the advanced, especially in biology and engineering, whereas social sciences and the humanities ranked much higher.

Could this be an intrinsic difference due to content factors between science and non-science areas? Strenta et al. (1994), Seymour and Hewitt (1994) and Gainen (1995) asked students to elaborate on their reasons for leaving or their general discontentment in SME areas. Results showed that students were generally interested in the sciences but were "turned off" by the structure and climate of the classroom.

Thus, the popularly misconceived notions in explaining attrition among SME majors, that of language problems with foreign assistants, large class sizes, and poor high school instruction, are not supported. Instead, an intimidating classroom climate, the poor quality of undergraduate SME instruction (particularly dull lecturing and poor academic advising), and a general lack of nurture for the student were cited most frequently (Seymour & Hewitt, 1997; Strenta et al., 1994). Gainen (1995) found that faculty may be able to reduce SME student loss rates by improving classroom climate changing from a competitive classroom structure and incorporating cooperative learning strategies to develop peer support.

personal contact with faculty

Student attitudes about faculty preoccupation with research and poor relations with students changed when students were allowed to participate in that research. The few students who had experienced this in Seymour and Hewitt's (1997) sample valued the open relationship between faculty and student in a research situation compared with the faculty's apparent indifference to them in a teaching context (Seymour & Hewitt, 1994). This finding is supported by Astin and Astin's (1993) and Newton and Wells-Glover's (1999) results, indicating that mentoring experiences in undergraduate SME areas are strong predictors of persistence. In addition, factors that contributed to the survival of SME students included regular personal contact with a particular instructor who took interest in them, departmental gatherings, and small group learning for discussion were significantly related to SME student retention (Strenta et al. , 1994).

The development of support networks and creating a more personalized educational experience with mentoring experiences were positively correlated with student retention particularly among female and minority college SME majors in studies by Newton and Wells-Glover (1999) and Hyde and Gess-Newsome (1999). Faculty development aimed at improving student-faculty relations in Engineering showed measureable in student retention and achievement at New Mexico State University (McShannon, 2001).

A frequent complaint among SME students in Seymour and Hewitt's (1997) study was inadequate personal contact with faculty during advisement. Many students traced their retention problems to improper faculty advisement. Over one third of both switchers and non-switchers felt that they were not made aware of the length of study (e.g. more than four years) required of SME majors and of the financial commitments needed to complete a program (Seymour & Hewitt, 1997).

cognitive ability differences

Seymour and Hewitt (1994) and Strenta et al. (1994) also found sufficient evidence to call into question the common explanation for attrition given by SME faculty: the inability of switchers to cope with the intrinsic "difficulty" of SME majors. First, they found a similarity between the proportion of switchers and non-switchers that experienced conceptual difficulties in SME areas (26.8% of switchers and 25.0% of non-switchers). However, no statistical analyses are given to support a null hypothesis.

In terms of acting as a factor in the decision to leave an SME major, conceptual difficulties were reported by only 12.6%. These conceptual difficulties were thought of as less important than 10 other concerns (primarily instructional) leading to switching decisions, overall (Seymour & Hewitt, 1994).

Seymour and Hewitt (1994) also found that most switchers worked hard and that their mean GPA just prior to leaving was at 3.0, not dramatically lower than the mean of current non-switchers GPAs (3.15). This finding is supported by the results of a study by Humphreys and Friedland (1992), who found that "students who persisted and students who switched earned comparable grade point averages (3.10 compared with 3.07)" (p.5).

Results by Loftin's (1993) study of 141 undergraduate persister and non-persister SME majors suggest that a student's gain in confidence from the introductory SME course and instructor presentation skills in that course are significant predictive factors contributing to student retention and recruitment. Cognitive ability, course rigor, and amount of student reading were not as strongly correlated with student retention and recruitment.

However, conflicting views of the contribution of cognitive skills to attrition exist. Strenta et al. (1994) reported that differences in persistence were significantly attributable to a single performance variable: grades in science courses in the first two years of college. There is disagreement here with Seymour and Hewitt's (1994) contention that non-persisters did equally well in SME courses as persisters.

It is thus possible to cast doubt on the chilly climate hypothesis because the achievement of lower grades could contribute to lower confidence in SME and negative student views of science instruction and classroom atmosphere. It is not a strong case, however, because Strenta et al. (1994) found that science majors as a whole (persisters and non-persisters) viewed their science courses differently from their non-science courses and that both persisters and non-persisters cited similar criticisms of the SME atmosphere (Seymour & Hewitt, 1994, 1997).

gender and minority-status as variables

Engineering and physics remain the most exclusively male-dominated science-based disciplines (McShannon & Derlin, 2000). In an analysis of national university enrollment and graduation data, minority women disproportionately fail to be recruited and retained in engineering and physics, with first-year enrollments declining in the 1990's (National Action

Council for Minorities in Engineering (NACME), 1996). The study blames student isolation within the engineering community and the use of a student-deficit model instead of institutional attempts to retain minority and female engineering students. McShannon & Derlin's (2000) study of 515 engineering students found that minority women were more successful in non-traditional learning patterns (e.g. cooperative learning styles) than their cohorts. This indicates that retention among underrepresented groups in SME areas would also be enhanced by changes in instructional styles that include multiple learning style approaches and a departure from the competitive "chilly climate".

differing expectations

The lack of consensus among high school and college educators about what introductory SME courses should entail may also contribute to the difficulties students face in their transition to college. Post-secondary teachers design their introductory courses with certain assumptions about the academic characteristics of incoming students (Mitchell, 1990; Razali and Yager, 1994). Secondary faculty develop curriculum to prepare students for successfullty engaging in college SME courses. According to studies by Daempfle (2000), Mitchell (1990) and Razali and Yager (1994) on college and high school SME faculty expectations, post-secondary instructors were shown to have different expectations for incoming student characteristics than secondary preparation addresses.

First-year college student difficulties may be related to an incongruity between secondary student preparation and post-secondary faculty requirements. Daempfle's (2000) study examined how well matched secondary and post-secondary teacher assumptions were about the student characteristics required for success in introductory college biology courses. Faculty participants from secondary, two-year, and four-year colleges were interviewed, engaged in focus groups, developed tables of specifications for student requirements, and responded to surveys. The results of this study indicated that secondary and post-secondary faculty have differing assumptions about the importance of certain student characteristics for success in college biology but that communication improved agreement on those assumptions between the two groups. Post-secondary faculty emphasized the importance of mathematics, writing skills, and integrating biology with other subject areas while secondary faculty valued content areas such as vocabulary knowledge and nomenclature skills (e.g. Latin usage) and dispositions such as self-discipline.

Differences in faculty expectations between secondary and post-secondary groups is also shown in studies by Razali and Yager (1994) and

Mitchell (1990). They demonstrate that there is a difference in the perceived importance of various college chemistry topics by college chemistry professors and high school chemistry teachers. Razali and Yager (1994) and Mitchell (1990) use survey instruments with college chemistry faculty and high school chemistry teachers in which they rate student characteristics that were classified into three different groups (knowledge, skill, and personal trait) in terms of their relative importance in preparation for success in college chemistry courses. A one-way analysis of variance showed statistically significant differences of perceived importance of the three categories between secondary and post-secondary groups (Razali & Yager, 1994). Statistically significant differences were also found between the two groups in Mitchell's (1990) study. High school chemistry teachers rated knowledge of chemistry (e.g. knowledge of chemical factors, definitions, generalizations) and skill in chemistry (e.g. processes, quantitative skills, and higher ability thinking) as significantly more important than what the college professors rated highest--personal traits (e.g. general study skills and personality features such as creativity, ingenuity, and imagination) (Razali & Yager, 1994). In concurrence with Daempfle's (2000) study, college faculty rate the attainment of SME concepts as the least important preparation for entering college and instead prefer incoming students to possess an ability to see the content within a framework that integrates other disciplines (Razali & Yager, 1994). The results imply that high school teachers who believe that the content they teach is important in preparation for college are, in fact, concentrating on something that college professors do not value highly in college SME courses.

epistemological assumptions

There is a growing body of evidence that indicates that student epistemological belief may affect academic performance and hence attrition. For instance, the more students believe in the certainty of knowledge, the more likely they are to interpret tentative information as absolute, thus leading to a difficulty in comprehending the essence of scientific progress--that of disproof of hypotheses and the continual change in accepted knowledge (King & Kitchener, 1997; Schommer, 1993; Freeman, MacNeil, Daempfle, Thusynma, & Uzoh, 1997).

In a study conducted by Ryan (1984), results on surveys allowing for rating of responses to certainty of knowledge questions indicated that the more college students believe in black and white interpretations of scientific phenomena, the more likely they are to oversimplify information, the poorer their overall academic achievement and confidence in science, and the higher the chances for attrition. This epistemological approach to interpreting attrition rates among SME majors links to the other research variables cited. Perhaps there is a relationship between the perception of a chilly climate among SME majors as cited by Seymour and Hewitt (1994) and poor academic performance of switchers, as cited by Strenta et al. (1994) with naive epistemological understandings of the nature of science. Students with right/wrong beliefs about knowledge could become disenfranchised when confronting the higher level epistemological demands required by SME professors, with the result of attrition.

In an attempt to further tease out the epistemological variables contributing to attrition, McDade (1988) used interview and survey data to describe non-persister perceptions of the SME field and determine their understanding of their personal choice to switch. Her findings indicate that non-persisters in SME majors tend to hold a view of knowledge as absolute. The majority of students showed a common orientation to science and math ways of knowing: They held an uncritical acceptance of science and math as factual descriptions of right and wrong answers; There was little critical examination of how this process of teaching and learning required only a narrow, superficial view of science; Most non-persisters considered science learning the acquisition of a thing--a product that could be obtained and useful as a college degree (a utilitarian purpose for obtaining a science education) (McDade, 1988).

disagreement in characterizing persisters and non-persisters

The work on epistemological differences between persisters and non-persisters in SME areas conflicts with the findings by Seymour and Hewitt (1994,1997). Seymour and Hewitt (1997) directly address this apparent discrepancy, stating of their results,

> our most important single generalization about switchers and non-switchers is that we did not find them to be two different kinds of people. That is, the reasons why students switched to non-SME majors were not rooted in attributes of character or ability (p.232).

Instead, reasons for switching arose due to a set of problems shared by both switchers and non-switchers, namely, the chilly climate hypothesis (e.g. Strenta, et al., 1994; Seymour & Hewitt, 1992,1994,1997; Astin & Astin, 1993).

It should be noted, however, that Seymour and Hewitt (1994,1997) and Strenta et al. (1994) studied only high ability students who may have differed in epistemological beliefs as compared with the epistemological studies that did not exclude lower ability switchers and non-switchers. Also, McDade (1988) did not compare switcher and non-switcher attributes specifically, discussing only switcher epistemological beliefs. Thus, although McDade's (1988) study appears to contradict Seymour and Hewitt's

(1994,1997) findings, in reality both contribute different perspectives on the identification of the factors involved in the SME attrition problem. It may well be that epistemological differences interact with other variables to precipitate a decision to switch from an SME major.

epistemological belief and two-year college transfers

There is a substantial body of evidence claiming that two-year college students are academically less developed as compared with those entering universities directly from high school, according to Schommer (1993). This has resulted in a higher attrition rate among two-year college transferees from the SME areas (Astin, 1977). Perhaps this retention problem can be attributed, in part, to a difference in epistemological beliefs between the two-year and four-year college classroom.

Schommer (1993) conducted a study which, in part, compares the epistemological assumptions of two-year college and university students. His results indicated that two-year college students were more likely to believe that knowledge is simple ($F(1,251)=10.12$, $p<.01$) and certain ($F(1,251)=4.23$, $p<.05$) and that learning is quick ($F(1,251)=3.92$, $p<.05$) than university students. This would suggest, according to Schommer (1993) that many two-year college students transfer to higher education with a "wide range of invisible barriers to higher level thinking" (p.366) which could lead to poorer overall academic performance and a higher attrition rate among community college transferees in SME areas.

In support of the view that certain epistemological beliefs are necessary for success in SME majors, an interview study conducted by Beers (1988) found that teachers were primarily concerned with imparting a particular set of epistemological ideals to their students and assessing the success of this teaching. However, because the study involved only one junior college and one university and did not concentrate on SME majors in particular, the results are very limited in explaining attrition among SME majors.

While limited in generalizability, the findings do lend support to Daempfle's (2000) and Razali and Yager's (1993) results showing that certain student characteristics (e.g. ability to integrate scientific knowledge with non-science areas; seeing the tentativeness of science) were valued above knowledge accumulation among college SME faculty (Beers, 1988). In one interview, a biologist, for example, said that she "hated facts and spoke of getting students excited about the way the world works" (Beers, 1988, p.87). Beer's (1988) work thus links to the studies on expectations in explaining attrition. If college faculty expect students to be able to "get excited" about the plausibility of sciencetific facts but secondary curriculum does not foster such a disposition, then such a mismatch in preparation could inhibit student achievement and retention.

DISCUSSION

faculty expectations

The conflicting views between high school teachers and college instructors in what incoming students in SME disciplines should possess suggest that college professors are advocating a change in the instructional approach for high school SME courses. The focus of the college faculty seems to be on the development of certain personal traits, according to the research, such as student creativity, imagination and inquisitiveness, the use of effective study skills, and an integration of non-science areas with the sciences (Daempfle, 2000; Razali and Yager, 1994). These results may be because college instructors deal with more mature and academically talented students and normally give lectures to large groups. They therefore would tend to expect students to be more independent learners than would high school teachers, who, by the nature of the secondary classroom, are able to offer a large degree of guidance (Razali and Yager, 1994).

This does not negate, however, the importance of the juxtaposing views of high school and college faculty in this study. When high school teachers are preparing students for college SME environments inappropriately, a contribution is clearly seen to the increased attrition rates in SME areas and the expansion of the gap between the two levels of schooling. More research is needed in areas of science (e.g. engineering and mathematics) to determine the extent of conflicting expectations among high school and college SME faculty.

epistemological expectations

The importance of epistemological assumptions underlying teacher expectations for incoming college SME majors probably plays a role in student success and hence, attrition. For example, if students are entering college from high school with a set of beliefs about knowledge that has been fostered by high school teacher expectations that do not match the epistemological objectives of college SME teachers, students are likely to be at a disadvantage. It would be interesting to see to what extent the differences in epistemological expectations among high school and college SME faculty contribute to attrition. Clearly, more research is needed to identify the influence of epistemological belief on attrition in two-year college transfers to university SME majors.

What implications do the results have for college and secondary programs with the goals of encouraging interest and persistence in science?

Schommer (1993) and McDade's (1988) results act as indicators that both two-year colleges and universities assess student epistemological beliefs. Several epistemological assessment measures have been described by King and Kitchener (1997) and Perry (1970), who studied knowledge claims in undergraduates. Schommer (1993) suggests that instruction should focus on modifying the epistemological beliefs of undergraduate students. Instruction might include several steps such as: (a) modeling desired epistemological positions in lectures and discussions, (b) clarifying epistemological purposes of a course in objectives and examinations that are consistent with the epistemology, and (c) understanding that epistemological beliefs are a possibility for poor student performance when providing remediation (Schommer, 1993).

Recommendations for Post-Secondary SME Courses

To reduce student loss rates in college SME courses, the research clearly points to a need to change the structure of the post-secondary SME classroom. To accomplish this, undergraduate SME instruction should shift from simple knowledge transmission to actively and cooperatively engaging students. Active student involvement in lectures, structuring assessment practices to include cooperative learning strategies, and increasing faculty involvement would improve student attitudes, achievement, and retention.

The mere presentation of content in introductory college courses without giving students opportunities for seeing how that knowledge fits within the whole curriculum does not further the kind of collateral, integrative learning advocated by the college faculty in the expectation studies by Daempfle (2000) and Razali and Yager (1994) and by the national and state secondary standards in SME areas. Although scientific factual knowledge is needed in the vertically-structured life sciences, it is only insofar as it can be used in higher order cognitive processes, which compare and connect the phenomena of a variety of academic areas (Dewey, 1938). The importance of Dewey's (1938) principle of continuity is thus recognized by these recommendations for content in post-secondary SME courses, whereby students engage in collateral, synthetic learning. This fosters "the most important attitude that can be formed[,]...that of a desire to go on learning" (Dewey, 1938, p.48).

To reach post-secondary faculty expectations, content learning demands for undergraduate SME students should thus "be considered intrinsically multidisciplinary. Student learning is enhanced when we are able to help students see the relationships among the sciences, and between science and mathematics, the humanities, social sciences, and the arts" (Committee on Undergraduate Science Education, 1997, p. 7). Rather than focusing on what amount of content is necessary, the organization of that content around themes, issues, or projects can enrich the students' view that life sciences are not separable from other areas of life and can be reasoned about in a more holistic way.

Despite these limitations, traditional lectures are the most common form of instruction in introductory SME courses (Committee on Undergraduate Science Education, 1997). While I would recommend a change from the lecture-oriented instruction, it may be practically unavoidable given the institutional policies on limiting instructors and maintaining high introductory course enrollments. A look to the literature on teaching and learning that contains instructional strategies to enhance student learning in lecture settings is beneficial. A synthesis of the research from Eble (1988), Davis (1993), Lowman (1995), and McKeachie (1994) offers a guide for post-secondary science lectures (Committe on Undergraduate Science Education, 1997): Use paradoxes and apparent contradictions to engage students; Make connections with other courses and everyday phenomena; Begin each class with something familiar to students; Delivery affects student motivation (e.g. eye contact; enthusiasm); Ask divergent over convergent questions.

When considering the final point, the type of questions asked are important to the kinds of reasoning processes students are encouraged to use and the kind of excitement brought to the lecture (Committee on Undergraduate Science Education, 1997). For example divergent type questioning such as "Why do birds produce uric acid as an excretory product?" would elicit a much more exciting and reasoned answer than the convergent, "What do birds produce as an excretory product?". Consider the first example. A student must elaborate on their prior knowledge that uric acid is a precipitate from chemistry class, that urea produced by humans would kill the bird embryo because it is soluble in the water within the shell (concepts from excretion in introductory biology), and that evolutionarily this is beneficial (a socio-historical principle). Alternate working hypotheses may be developed through class discussion focusing on, for example, the conservation of water in excreting uric acid instead of urea. The reasoning moves beyond the mere acquisition of the fact that birds make uric acid and enhances the kind of collateral thinking that would create a more interesting and less "chilly" classroom, with student creating knowledge collaboratively (Daempfle, 1999).

Institutional Recommendations

An active research program, perhaps tracking non-persisting students in biology and exploring their reasons for leaving, would be beneficial to institutional retention. Action at the institutional level is supported by this study in accordance with the National Action Council for Minorities in Engineering's (1996) conceptual framework for student retention as an institutional issue. Because a mismatch in student preparation between secondary and post-secondary SME programs is plausible, safeguards against student loss should be implemented. These might include: remediative courses or workshops to lessen possible academic deficiencies caused by preparation discrepancies, counseling services to help students cope with academic adjustments during their transition to college SME courses, and recruitment of faculty willing to participate in research and communication that improves the congruence of student preparation.

CONCLUSIONS

Thus this review clarifies and interprets the interaction of those characteristics of the structure and culture of undergraduate science education programs that perpetuate high loss rates among first-year college SME majors. The interaction of instructional factors, differing high school and college faculty expectations for entering SME undergraduates and epistemological considerations could contribute to a higher dissatisfaction found among SME majors and the resulting attrition. Support was not seen for the contribution of commonly cited explanations of attrition such as cognitive variables and large class sizes.

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