Survey of Biology Capstone Courses in American and Canadian Higher Education: Requirement, Content, and Skills

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Abstract: Capstone experiences have high educational impact with various approaches available for biology. However, no information exists regarding the pervasiveness of capstone courses in Canadian and American biology programs. This study surveyed the prevalence and character of biology capstone courses in the USA and Canada. The survey included a majority of public institutions offering primarily undergraduate programs. Seventy percent of American biology degree programs required a capstone course vs 27% of Canadian schools. Large and graduate institutions were less likely to require a capstone course. Medium-sized institutions were more likely to deliver their biology capstone course as a seminar, whereas small institutions were more likely to include an undergraduate research experience. Sixty percent provided some review of biology's conceptual foundations, but most capstone courses devote little time considering the history or philosophy of biology. Most schools included the development of students' writing, speaking, and thinking as learning objectives. Research skills were significantly less likely to be a learning objective. Although biological capstone courses may intend to integrate students' biological knowledge, educators also need to consider how that knowledge could be synthesized into students' entire education.

Keywords: curriculum, research, communication, thinking, history, philosophy

INTRODUCTION

High impact educational practices positively impact student learning outcomes (Brownell and Swaner, 2010, Julien et al., 2012). Capstone experiences are one such practice which facilitate students' integration of their learning; students are able to construct a robust knowledge structure for themselves when their knowledge is interconnected and integrated into a whole rather than fragmented into a series of unconnected courses (Levine, 1998, Kuh, 2008). Different strategies for delivering capstone experiences exist (Smith, 1998): They may be delivered through the major discipline (Stanford and Duwel, 2013), as a general education requirement (Griffin and Burns-Ardolino, 2013, Kerrigan and Carpenter, 2013), or be an experience not tied to an individual course (Redman, 2013, Wenk and Rueschmann, 2013). In addition, capstone courses may not be restricted to students' final year of a degree program instead integrating students' associate degree program (Stubbs et al., 2013) or serving to introduce a discipline (Chaplin and Hartung, 2012).

A variety of approaches exist for providing capstone experiences within the biology major. They may involve journaling or writing courses that promote critical thinking (Lankford and vom Saal, 2012). Some develop students' communication skills (Obringer and Kent, 1998). Other possible approaches include a comprehensive final exam, literature review, research presentation, exit interview, or e-portfolio (Davis, 2011, Stanford and Duwel, 2013). Alternatively, honours theses delivered as an independent studies course (Levine, 1998) including an undergraduate research experience (Brownell and Swaner, 2010) may serve as a capstone experience. Capstone experiences do not need to be delivered as a course but could be a requirement for completing a major (Davis, 2011). However, if a capstone experience is not integrated into a particular course it may become extra workload within a full course load for students.

Although these many ideas for capstone experiences have been discussed in the published literature, nothing exists to indicate the degree to which capstone courses have been implemented in Canada and the USA and the content and skills that are taught within them. An earlier survey of the general biology curriculum indicated that students and faculty were interested in an integrative senior course, but was not widely considered at that time (Carter et al., 1990). The survey reported in the present paper fills this gap in our curricular knowledge by determining whether American and Canadian institutions of higher education require students to complete a capstone course in partial fulfillment of their biology degree program. The survey also reports on the nature of biology capstone courses, in addition to their mode of delivery.

METHODS

An online survey using Google Forms was constructed asking institutions to indicate the nature of their institution describing it as either public or private, and whether it was a two-year community college, undergraduate college, or research university. The survey also asked participants if a capstone course was offered as part of their biology major and whether that capstone was a required course. In addition, the survey asked respondents to indicate the nature of the course in terms of its delivery, the content being learned, and which skills were being developed in their students. The last question provided participants the opportunity to include any other noteworthy characteristics of their capstone course not captured in the survey.

The link to the online survey instrument was emailed to all institutions that offered a major in biology (as indicated by their website) that were members of representative American and Canadian organizations of higher education (N = 446) including: American Association of State Colleges and Universities (AASCU, 2014), Council of Public Liberal Arts Colleges (COPLAC, 2014), Association of Universities and Colleges of Canada (AUCC, 2014), and Alberta Introductory Biology Association (AIBA, 2014). These four organizations form a representative population of biology programs offered in Canada and the USA. The email was sent directly to a biology representative or administrator as indicated on the institution's website requesting that the survey be completed by whomever best understood the biology program or teaches the biology capstone course. An emailed follow-up was sent to each member who had not responded to the survey within four weeks. Some institutions were members of more than one organization but were only entered into the survey once. The surveyed population consisted of only those institutions offering a biology major as determined from each university and college's website. American protectorates and international members of AASCU were not included. Institution size was determined from 2013 enrollment data obtained from the AUCC website (AUCC, 2014) and IPEDS Data Center (US Dept of Education et al., 2013) using head counts which included the number of undergraduate, graduate, full time, and part time students. This enrolment data was used to categorize institutions into small (<5,001 students), medium (5,001-15,000 students), and large (>15,000 students) institutions. Primarily undergraduate institutions offered few, if any, graduate programs.

Survey confidence intervals were calculated at a confidence level of 95% when the total population size was known. Significant differences among regions and institutional sizes and types were determined using chi-square analysis. In some cases, however, an expected cell value in the contingency table was less than one, or more than 20% of the expected values were less than five producing an unreliable chi-square analysis. In these cases Fisher's Exact Test was used. Tukey's test determined the statistical significance among the ranked proportion of a biology capstone course which reviewed fundamental biological concepts, or considered the history and philosophy of biology.

RESULTS

The survey generated an overall 40% response (N = 177). There was no response bias by instituion size ($X^2 = 0.898$, $p = 0.638$), type ($X^2 = 0.658$, $p = 0.417$), or region ($X^2 = 1.987$, $p = 0.851$). The vast majority of responding institutions were public (98%) consisting primarily of undergraduate or research institutions offering four-year bachelor degrees. Two of the responding institutions were two-year colleges and were included in the survey analysis because associate degree programs may require capstone courses (Stubbs et al., 2013). Indicative of the differences between the Canadian and American context, the Canadian sample had a significantly greater proportion (73%) of research institutions responding to the survey relative to the American response (28%; $X^2 = 15.55$, 1 DF, $p < 0.0001$). The response sample had a greater proportion of public institutions from the US (99%) than from Canada (88.5%, Fisher's Exact Test $p = 0.0103$). There were no significant regional differences among Eastern or Western Canada or the American West, Midwest, Northeast or South. Large institutions were significantly less likely to be undergraduate (25%) institutions than medium (83%) or small (92%) institutions (Fisher's Exact Test $p = 0.0489$). In contrast, small institutions were less likely to be public (92%) than medium and large institutions (99% and 100%, respectively; $X^2 = 67.06$, 2 DF, $p < 0.001$).

Sixty-three percent of responding institutions indicated that their biology degree programs require students to complete a capstone course (Figure 1). However, only 27% of Canadian vs 70% of American biology degree programs require their students to complete a biology capstone course in partial fulfillment of the biology major ($X^2 = 15.55$, 1 DF, $p < 0.0001$), although another 23% of responding Canadian institutions offer a biology capstone course but do not require it. Less than 10% of all responding biology degree programs indicated either that: i) they offered a capstone course but did not require it; ii) had discontinued their capstone course; iii) their biology program was subdivided into different sub-fields (e.g. zoology, botany, ecology, wildlife biology, biotechnology, molecular biology) but that not each offered a capstone course; iv) students complete a capstone as part of their general education requirements but not necessarily as a biology course. Large and research institutions were significantly less

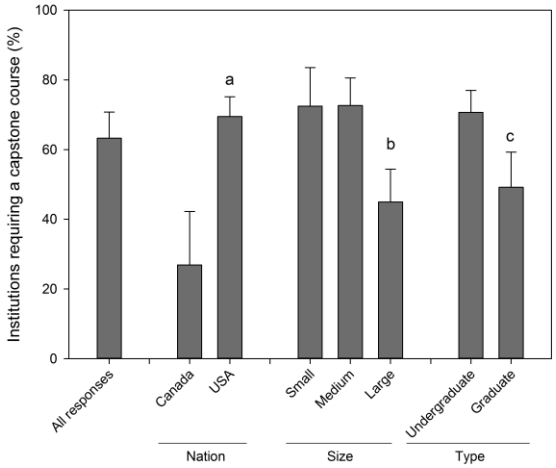

Fig. 1. Prevalence of biology capstone courses among responding institutions (N=177). Error bars indicate confidence interval at the 95% confidence limit. Chi-square analysis detected significant differences: [a]American institutions are more likely to offer a required biology capstone course ($X^2 = 15.55$, 1 DF, $p < 0.0001$); [b]Large institutions are less likely to require a biology capstone course ($X^2 = 13.05$, 2 DF, $p = 0.0015$); [c]Primarily undergraduate institutions are more likely to offer a required biology capstone course ($X^2 = 7.06$, 1 DF, $p = 0.0079$).

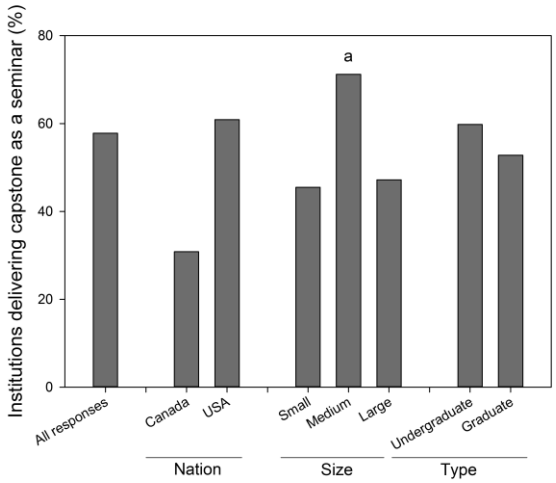

Fig. 2. Percentage of biology capstone courses offered as a seminar. Percentages are of those institutions (N=128) offering a capstone course in their biology major. Confidence intervals are not reported because the total population size of institutions offering a biology capstone course is unavailable. Chi-square analysis detected significant differences: [a]Medium sized institutions tend to deliver their capstone course as a seminar ($X^2 = 8.05$, 2 DF, $p = 0.018$).

likely ($X^2 = 13.05$, 2 DF, $p = 0.0015$ and $X^2 = 7.06$, 1 DF, $p = 0.0079$, respectively) to require the completion of a capstone course by their students majoring in biology.

The delivery of surveyed biology capstone courses was approximately split among all respondents between seminar (58%) and lecture (42%) (Figure 2). However, medium-sized institutions were significantly more likely than small or large institutions to deliver their biology capstone course as a seminar (71% vs 46% and 47%, respectively; $X^2 = 8.05$, 2 DF, $p = 0.018$). The inclusion of an undergraduate research experience (URE) in responding biology capstone courses was also split (54% included a URE) among all respondents (Figure 3). Small institutions, however, were statistically more likely than medium or large sized institutions to include a URE in their biology capstone course (73% vs 42% and 53%, respectively; $X^2 = 7.83$, 2 DF, $p = 0.020$; Figure 3). American biology capstone courses were twice as likely as Canadian courses to be delivered as a seminar (61% USA vs 31% Canada), and the inclusion of a URE was more likely in Canadian capstone courses than in American (69% Canada vs 51% USA) though these differences were not significant. In addition, there were no statistical differences between primarily undergraduate or graduate/research institutions: Both types of institution were approximately split between delivering the biology capstone as a seminar vs lecture, and between whether or not the capstone included a URE.

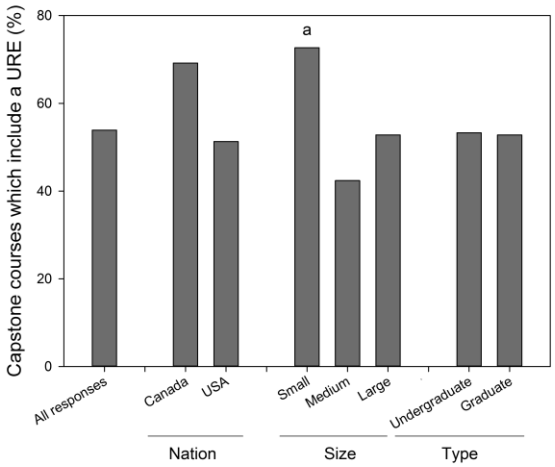

Fig. 3. Percentage of biology capstone courses which include an undergraduate research experience (URE). Percentages are of those institutions (N=128) offering a capstone course in their biology major. Confidence intervals are not reported because the total population size of institutions offering a biology capstone course is unavailable. Chi-square analysis detected significant differences: [a]Capstone courses at small institutions are more likely to include an undergraduate research experience ($X^2 = 7.83$, 2 DF, $p = 0.020$).

There were no significant differences between Canada and the US, between primarily undergraduate and graduate/research institutions, or among the three institutional sizes with regard to the content taught in biology capstone courses: Most do some review of biology's conceptual foundations (60%), while most do not consider history or philosophy of biology (55% do not). Canada, however, was less likely to review biology's conceptual foundations (39% vs 62% in the US) though this difference was not significant.

When the amount of time devoted to considering biology's conceptual foundations, history or philosophy, is more closely examined (Figure 4) it becomes clear that most Canadian and American institutions spend little to no time considering these issues. American and Canadian institutions were significantly less likely to consider the history and philosophy of biology (56% and 55% indicated no consideration whatsoever, respectively) than to review its conceptual foundations (40% indicated no review whatsoever; Tukey test, $p < 0.05$). Significant differences were not detected among nations, regions, or sizes and types of institution.

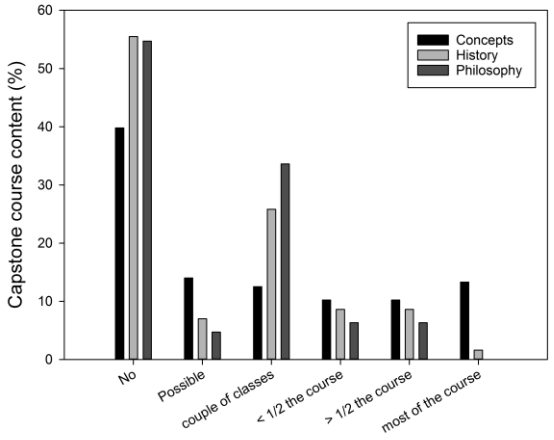

Fig. 4. Percentage of institutions offering capstone courses which consider the major foundational concepts, history, and philosophy of biology. Percentages are of those institutions (N=128) offering a capstone course in their biology major. Confidence intervals are not reported because the total population size of institutions offering a biology capstone course is unavailable. The Tukey Test indicated a significant difference ($p < 0.05$). The history and philosophy of biology are less likely than foundational concepts to be covered in biology capstone courses among all institutions (N=128) when the categories were converted into ranked values: No = 0, Possible = 1, Couple = 2, < ½ = 3, > ½ = 4, Most = 5.

Most responding institutions indicated that the development of students' writing, speaking, critical thinking, and research skills are learning objectives of their capstone course (Figure 5). The development

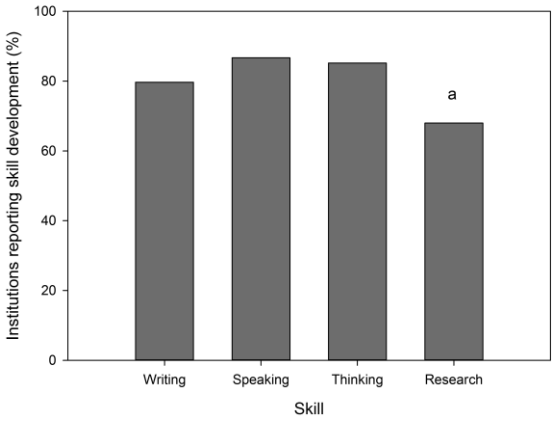

Figure 5. Percentage of institutions indicating that the development of a particular skill is a learning objective of their capstone course. Percentages are of those institutions (N=128) offering a capstone course in their biology major. Confidence intervals are not reported because the total population size of institutions offering a biology capstone course is unavailable. [a]Chi-square analysis detected significant differences among the different skills being developed in students among all responding institutions ($X^2 = 17.25$, 3 DF, $p = 0.00006$). The development of students' research skills was less likely to be a learning objective of the course than writing, speaking, or critical thinking.

of students' research skills (68%), however, was significantly less likely to be a learning objective of the course than the development of students' writing, speaking or critical thinking skills (80%, 87%, 85%, respectively; $X^2 = 17.25$, 3 DF, $p = 0.00006$).

The survey permitted participants to include any comments that would better clarify the nature of their capstone course. From these comments it appears that the most common capstone course of biology degree programs involves students researching a question, and reporting their results in a formal paper and public presentation. There were variations on this approach with some being embedded in a single course or spread over two courses. In addition, the research could involve the collection of lab or field data, or be restricted to the current literature to produce either a review paper or simulated grant application.

Other examples of capstone courses included those which involved either guest or student-led seminars discussing current topics in biology or applied students' biological knowledge to a term-long theme (e.g. global warming or the impact of agricultural practices) connecting to other disciplines with evolution as the most common unifying theme. A few institutions indicated that their capstone courses prepared students for the work world (e.g. résumé and cover letter preparation) including graduate school applications. In addition, some

capstone courses prepared students for externally administered assessments of student learning (e.g. Major Field Test in Biology, Area Concentration Achievement Test) as required for accreditation. One survey respondent commented that the external assessment for accreditation did not provide information different from what they had gathered from their own internal tests and student grades, and that the preparatory course was not of the same educational value as their other biology courses. One university indicated that their general education requirements include visual literacy which could be satisfied by the biology capstone course. Visual literacy in this capstone involved teaching students to understand scientific information presented in tables, graphs, and other visual representations. Three institutions reported that their capstone courses consider ethical issues in biology including research, biomedical, and environmental ethics. One institution commented that the communication learning objective of their capstone course involved everything necessary for networking in science including the use of technology that enables remote meetings, conferencing, sharing information, and accessing work groups. Finally, there was one institution that reported that their biology capstone course was run as a journal club with articles chosen by the instructor.

DISCUSSION

While department chair, I regularly discussed students' educational programs when they registered for their subsequent year of study. Their program planning form was a single page which organized their required courses into lists of boxes that needed to be checked off before being eligible to graduate. My difficulty was that students' learning seemed to be reduced to a series of disconnected courses with little integration or cumulative learning (Smith, 1998). In the courses I taught, students seemed to approach their education using a memorize-regurgitate-purge learning cycle with the result that their learning did not inform their next educational experience. Students busy themselves collecting courses but never take the time or are never granted the opportunity to build for themselves an integrated knowledge structure: The bricks (courses) remain in a pile in a corner of the lot never being used to construct a house (Smith, 1998). At some institutions the lack of integrative, cumulative, or reflective learning may be a result of the professionalization of the professoriate producing a greater commitment by faculty to the needs of the discipline rather than to the needs of student learning (Smith, 1998). To enable students to integrate their learning, undergraduate degree programs need to scaffold their educational experiences such that students are able to interconnect their knowledge gained from different courses and experiences, leading to deeper learning and a more robust knowledge structure (Ambrose et al., 2010). There are many possible learning structures that can integrate students' cumulative learning (Smith, 1998): learning communities, ability or skills based education, service and experiential learning, summative self-evaluations involving reflexive learning as might occur within an e-portfolio, and capstone courses.

Capstone courses are integrative experiences typically near the end of students' degree programs that tie together the disparate parts of an education (Smith, 1998) and have been shown to produce positive learning outcomes in physiology (Julien et al., 2012). Similar studies have not been published for biology degree programs. Other roles for capstones include providing breadth to move students beyond the narrow confines of their major, enabling students to apply their cumulative knowledge to solve or answer a problem or question, and finally to prepare students for their transition to a post-undergraduate reality (Levine, 1998). Courses are one vehicle of providing students a capstone experience. Others include comprehensive examinations and senior theses or projects (Levine, 1998, Davis, 2011, Kinzie, 2013).

The present survey suggests that American and Canadian capstone courses include many of these possibilities for integrating students' education but that the most prevalent form of biology capstone includes a research assignment which is presented as a formal paper and oral presentation similar to what has been previously reported for the academy at large (Kinzie, 2013) and for biology in particular (Stanford and Duwel, 2013). Some schools such as Allegheny College have strengthened students' performance in their senior capstone project by scaffolding the development of research skills throughout students' undergraduate years (Coates et al., 2014). Other examples from the current survey included preparing students for an accrediting assessment tool, preparation for the work world after graduation, and current biological topics seminars.

The advantages of seminars may include the introduction of students to a range of approaches to a discipline (de Pillis and Adolph, 2010) with student-led seminars developing students' communication, information literacy, and critical analysis skills (Obringer and Kent, 1998). The strength of student-led seminars is the active learning this entails as a result of students talking to, and teaching each other (Tanner, 2009) that can lead to deeper learning (Weimer, 2013) relative to lectures which have been documented to have less impact on student learning (Bligh, 1998). Some might argue that guest-led seminars are no different than lectures; however, it has been suggested that a passionate speaker who is invested in the material and who treats the subject matter with respect can have a deep impact on students' thinking (Palmer, 2007) exposing students

to current research and potential careers in the biological sciences. The present survey indicated that students were as likely to experience their capstone course as a seminar whether they were enrolled in an undergraduate college or in a research university, and whether they were attending a Canadian or American institution. Thus, from the results of the present survey there is clearly a diversity of approaches to capstone courses in biology degree programs which may reflect the different understandings of the learning outcomes for such a learning experience: application of biological research skills, integration of biological concepts, placing biological knowledge in its broader context to solve real-world problems, and to prepare students for life after their biology major. In addition capstone courses may facilitate institutional assessment of their own degree programs.

Undergraduate research is a high impact educational practice resulting in improved student learning outcomes (Fechheimer et al., 2011, Haave and Audet, 2013). However, many of the surveyed biology degree programs did not report the inclusion of an undergraduate research experience (URE) in their capstone course. If it is not part of the capstone, does it happen elsewhere in students' degree programs? At Augustana, for example, our biology capstone does not include a URE but students are required to complete another senior course in their fourth year: most of our fourth-year courses include a URE. Thus, our biology degree program does not ensure that all of our students have a URE. Promising students are directed to our independent studies courses which will provide them with a URE, but not all students are so directed. Is this an important consideration? Is it important that all biology students graduate with a URE even though most will not become practicing biologists? Or is it more important for biology students to graduate with a sense for how our biological concepts impact how we interact with each other and design our communities? For example is it important for students to consider whether our biological understanding indicates whether we are biologically, environmentally, and/or culturally determined and should that affect how we design and implement our community programs? These are integrating questions that biologically informed citizens need to consider. On the other hand, UREs develop skills important to any community leader: speaking, writing, critical thinking, and gathering and assessing data and information, in addition to producing self-reliance (Brownell and Swaner, 2010). Any assumption that research institutions provide more research opportunities for undergraduate students is not supported by the data presented here similar to what has been previously reported (Hu et al., 2007). A previous survey of the general biology curriculum had indicated that smaller colleges were providing greater opportunities for undergraduate research than at large universities (Carter et al., 1990). The current survey indicates that small institutions are more likely to provide a URE within their biology capstone course but that there is no difference when primarily undergraduate institutions are compared with graduate institutions. It seems that size does matter when it comes to providing students with a URE.

The current survey indicated that the vast majority of biology capstone courses do not review its conceptual foundations. Is it safe to assume that students have a sufficient grasp of biology's theoretical foundations? Typically students' freshman biology course(s) considers biology in its whole but never again throughout their program. Do students need another chance to integrate their biological knowledge after completing higher level studies in biology to avoid compartmentalization of their knowledge structure? If the central tenets of biology rest on the interdependence of biological function, development, and evolution (Haave, 2012) then perhaps students should be given the chance to integrate their deeper knowledge gains after the disciplinary focus that typically happens in students' sophomore and junior years.

Very few institutions included discussion of the historical and philosophical foundations of biology in their capstone courses possibly indicating that their understanding is not considered significant to the practicing biologist or informed citizen. However, without a grounding in the philosophical assumptions of modern biology, or a grasp of the historical contingencies that produced a biological science focused on molecules with little consideration of ontogeny may produce graduates with little understanding of the types of questions that have been the most productive in advancing our biological knowledge and why they have been successful in doing so (Hawke, 1983). A consideration of the history and philosophy of biology can also illuminate why particular biological fields languish as a result of having unclear questions or inappropriate tools for their investigation. In addition, placing our current biological understanding in the context of its history may increase students' engagement in the discipline. It has been argued that including the stories of biological researchers gives biology a human face to which students can relate and helps place biology in its social context; this enables students to consider the implications of biological research and how it is a social endeavour (Chamany et al., 2008). Doing so may provide students a sense of their own possible place in the biological sciences.

The literature suggests that capstone experiences have a positive impact on students (Brownell and Swaner, 2010), and the present survey indicates that most biological degree programs require them. It is unknown from this survey how students' undergraduate biology program is integrated beyond

their freshman year when a capstone is not offered. Capstone courses are one way to integrate a broad education, though if the capstone is embedded in the major its ability to do so may be limited (Kinzie, 2013). Attending to the historical and philosophical underpinnings of biology may be one way to achieve integration of the biology major into students' broader knowledge structure (Hawke, 1983).

To summarize, the present survey of Canadian and American biology degree programs produced a 40% response with most responding institutions being public undergraduate institutions. Most responding institutions required the completion of a capstone course by their biology students, though not so much in Canada or in large, research institutions. Biology capstone courses are as likely to be delivered as a seminar as they are as a lecture, though in medium-sized institutions the seminar predominates. In addition, an undergraduate research experience has an even chance of being a part of the capstone course though in small institutions this is more likely to happen. The majority of biology capstone courses have the development of students' communication and thinking skills as learning objectives including research skills to a lesser extent. Most capstone courses do not consider the history or philosophy of biology and spend little time reviewing the conceptual foundations of biology. It is apparent that biological capstone courses are primarily intended to integrate students' biological knowledge structure. Consideration of how that might be synthesized into students' entire education may be warranted.

ACKNOWLEDGEMENTS

Thanks to Alysha Wagner who assembled the data set as part of a CTL Summer Studentship from the University of Alberta. The data discussed in this paper were presented in part by NCH at the 58th annual meeting of the Association of College and University Biology Educators (ACUBE), University of Portland, OR, October 17, 2014

REFERENCES

AASCU. 2014. Strategic Plan - Governing Ideas. Accessed from http://www.aascu.org/strategic-plan/governing-ideas/ on 24 Oct 2014.

AIBA. 2014. About Us. Accessed from http://www2.mtroyal.ca/~tnickle/AIBA/AIBA_website/About_Us.html on 25 Oct 2014.

AMBROSE, S. A., BRIDGES, M. W., DIPIETRO, M., LOVETT, M. C. AND M. K. NORMAN. 2010. How does the way students organize knowledge affect their learning? Pp. 40–65 *How Learning Works: Seven Research-Based Principles for Smart Teaching*. Jossey-Bass Publishers, San Francisco, CA.

AUCC. 2014. About us. Accessed from http://www.aucc.ca/about-us/ on 24 Oct 2014.

BLIGH, D. A. 1998. Evidence of what lectures achieve. Pp. 10–23 *What's the Use of Lectures?* (5th edition). Intellect, Exeter.

BROWNELL, J. AND L.E. SWANER. 2010. Five *High-Impact Practices: Research on Learning Outcomes, Completion and Quality*. Association of American Colleges and Universities (AAC&U), Washington D.C. 68 p.

CARTER, J. L., HEPPNER, F., SAIGO, R. H., TWITTY, G. AND D. WALKER. 1990. The state of the biology major. *Bioscience* 40(9): 678–683.

CHAMANY, K., ALLEN, D. AND K. TANNER. 2008. Making biology learning relevant to students: Integrating people, history, and context into college biology teaching. *CBE-Life Sciences Education* 7(3): 267–278.

CHAPLIN, S. B. AND N. Z. HARTUNG. 2012. Integrative biology: A capstone course for an introductory biology core. *Journal of College Science Teaching* 42(1): 31–39.

COATES, E. L., KNUPSKY, A. AND M.S. CABALLERO. 2014. Charting a required senior capstone: Diverse scaffolding for transformative experiences. *CUR Quarterly* 34(4): 10–15.

COPLAC. 2014. About us. Accessed from http://www.coplac.org/about/ on 24 Oct 2014.

DAVIS, T. A. 2011. The biology major capstone experience: Measurements of accountability. *Bioscene: Journal of College Biology Teaching* 37(1): 26–28.

FECHHEIMER, M., WEBBER, K. AND P.B. KLEIBER. 2011. How well do undergraduate research programs promote engagement and success of students? *CBE-Life Sciences Education* 10(2): 156–163.

GRIFFIN, C. B. AND W. BURNS-ARDOLINO. 2013. Designing and implementing an integrative, collaborative, problem-solving-based general education capstone. *Peer Review* 15(4): 20–23.

HAAVE, N. 2012. Integrating functional, developmental and evolutionary biology into biology curricula. *Bioscene: Journal of College Biology Teaching* 38(2): 27–30.

HAAVE, N. AND D. AUDET. 2013. Evidence in support of removing boundaries to undergraduate research experience. *Collected Essays on Learning and Teaching* 6: 105–110.

HAWKE, S. D. 1983. Liberal arts and the biology seminar experience. *Journal of College Science Teaching* 13(2): 88–90,128.

HU, S., KUH, G. D. AND J. G.GAYLES. 2007. Engaging undergraduate students in research activities: Are research universities doing a better job? *Innovative Higher Education* 32(3): 167–177.

JULIEN, B. L., LEXIS, L., SCHUIJERS, J., SAMIRIC, T. AND S. MCDONALD. 2012. Using capstones to develop research skills and graduate capabilities: A case study from physiology. *Journal of University Teaching and Learning Practice* 9(3): article 6.

KERRIGAN, S. AND R. CARPENTER. 2013. Culminating a college education while fostering civic agency. *Peer Review* 15(4): 16–19.

KINZIE, J. 2013. Taking stock of capstones and integrative learning. *Peer Review* 15(4): 27–30.

KUH, G. D. 2008. *High-Impact Educational Practices: What They Are, Who Has Access to Them, and Why They Matter.* American Association of Colleges and Universities (AAC&U), Washington, DC. 35 p.

LANKFORD, D. AND F. VOM SAAL. 2012. Converting a biology course into a writing-intensive capstone course: Using collaboration between a professor and graduate teaching assistant. *Journal of College Science Teaching* 41(4): 15–22.

LEVINE, A. 1998. A president's personal and historical perspective. Pp. 51–59 In Gardner, J. N., Van der Veer, G. & Associates (eds.). *The Senior Year Experience: Facilitating Integration, Reflection, Closure, and Transition*. Jossey-Bass Inc., Publishers, San Francisco, CA.

OBRINGER, J. W. AND J. S. KENT. 1998. The senior biology seminar - A capstone course. *Journal of College Science Teaching* 27(4): 263–266.

PALMER, P. J. 2007. Teaching in community: A subject-centered education. Pp. 117–144 *The Courage to Teach: Exploring the Inner Landscape of a Teacher's Life* (10th edition). John Wiley & Sons, Inc., San Francisco, CA.

DE PILLIS, L. AND S. C. ADOLPH. 2010. Mathematical biology at an undergraduate liberal arts college. *CBE Life Sciences Education* 9(4): 417–21.

REDMAN, P. 2013. Going beyond the requirement: The capstone experience. *Peer Review* 15(4): 12–15.

SMITH, B. L. 1998. Curricular structures for cummulative learning. Pp. 81–94 In Gardner, J. N., Van der Veer, G. & Associates (eds.). *The Senior Year Experience: Facilitating Integration, Reflection, Closure, and Transition*. Jossey-Bass Inc., Publishers, San Francisco, CA.

STANFORD, J. S. AND L. E. DUWEL. 2013. Engaging biology undergraduates in the scientific process through writing a theoretical research proposal. *Bioscene: Journal of College Biology Teaching* 39(2): 17–24.

STUBBS, N. J., FEIBEL, A. AND P. ARCARIO. 2013. Integrative learning in the liberal arts: From cluster to capstone. *Peer Review* 15(4): 24–26.

TANNER, K. D. 2009. Talking to learn: Why biology students should be talking in classrooms and how to make it happen. *CBE-Life Sciences Education* 8(2): 89–94.

US DEPT OF EDUCATION, INSTITUTE OF EDUCATION SCIENCES AND NATIONAL CENTRE FOR EDUCATION STATISTICS. 2013. Look up an institution. Accessed from http://nces.ed.gov/ipeds/datacenter/InstitutionByName.aspx on 29 Oct 2014.

WEIMER, M. 2013. Research: Evidence that learner-centered approaches work. Pp. 28–55 *Learner-Centered Teaching: Five Key Changes to Practice* (2nd edition). Jossey-Bass, San Francisco, CA.

WENK, L. AND E. RUESCHMANN. 2013. Hampshire College's Division III: To know is not enough. *Peer Review* 15(4): 8–11.