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The Status of Capstone Courses for Pre-Service Secondary Mathematics Teachers

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Abstract

Capstone courses have been recommended as a way for pre-service secondary mathematics teachers (PSMT) to connect the mathematics they learn in university to the mathematics they will teach in high schools. However, not much is known about the nature of these courses in the U.S. Through a survey of departments of mathematics and education, the study presented here explored whether such courses were offered to PSMT and, if offered, how the courses were designed. Respondents reported on alignment with CBMS guidelines, curriculum, and assessments among other course logistics. Implications include: few capstone courses align with national guidelines and vary greatly.

Keywords: capstone course, mathematics teacher preparation, secondary mathematics

Introduction

There has been substantial discussion in the mathematics education community about the coursework required of pre-service secondary mathematics teachers. Secondary mathematics teacher preparation programs typically require pre-service teachers to complete a mathematics major, or the equivalent (Artzt, Sultan, Curcio, & Gurl, 2011; Conference Board of the Mathematical Sciences (CBMS), 2001), along with education coursework and some type of field experience. However, Hodgson (2001) noted that pre-service secondary mathematics teachers "have no explicit occasion for making connections with the mathematical topics for which they will be responsible in school, nor of looking at those topics from an advanced point of view" (p. 509). He endorsed the inclusion of undergraduate coursework that would help pre-service teachers develop "deep conceptual understanding of the school mathematics content" (p. 512). Likewise, the CBMS (2001) recommended that pre-service secondary mathematics teachers complete "a 6-hour capstone course connecting their college mathematics courses with high school mathematics" (p. 8). Since that time, there have been a handful of papers describing individual courses that satisfy Hodgson's and the

CBMS recommendations (e.g., Artz et al., 2011; Hill & Senk, 2004; Loe & Rezak, 2006; Van Voorst, 2004). Thus far, however, there has been no investigation of the extent or characteristics of the capstone course's varied forms at post-secondary institutions. With that in mind, the study described in this article aimed to answer following questions: What is the status of capstone courses in secondary mathematics teacher preparation programs? To what extent have the capstone recommendations from the CBMS report been put into practice over the last decade?

Herein, we present results from a 2011 survey of colleges and universities that offer such a mathematics capstone course, either in the department of mathematics or in the college of education, for mathematics majors intending to be secondary teachers (i.e., pre-service secondary mathematics teachers). The goal of the survey was to investigate the status of capstone courses in the United States and the extent to which capstone courses align with the CBMS recommendations. For the purposes of the survey, a *capstone course* was defined as a course taken at the conclusion of a program of study for pre-service secondary mathematics teachers that places a primary focus on providing *at least one* of the following: (1) bridges between upper-level mathematics courses, (2) connections to high school mathematics, (3) additional exposure to mathematics content in which students may be deficient, and/or (4) experiences communicating with and about mathematics (Loe & Rezak, 2006). The survey included questions about capstone characteristics such as the title, duration, department in which it is housed, textbook(s), and other resources used in the course. Additional data was collected about the description of the capstone course in university catalogs, the course goals, the instructional style, and the content (mathematical and otherwise) addressed. To provide a more complete picture of the current state of capstone courses, data was also collected about instructors' backgrounds and their levels of academic freedom.

Methodology

From 1,713 institutions listed by the Carnegie Foundation for the Advancement of Teaching (Carnegie Classifications, 2011), a stratified random sample of 200 institutions, weighted appropriately for each of nine classification groups (e.g., PhD granting institutions-high research activity, Master's Colleges and Universities-larger programs), was selected. A 23-question survey was developed and then implemented using Qualtrics online survey software and sent to each of these 200 institutions. The first two survey questions inquired about whether the institution had a capstone course that aligned with the definition of capstone course adapted from (Loe & Rezak, 2006), provided above. Survey respondents who affirmed that their institution offered such a course were then prompted to answer 21 additional questions. These questions were created and refined by the research team to collect a range of information regarding the status and nature of capstone courses. While some questions were open-ended, most provided choices from which the respondent could select an answer(s) to the question with an option for the reader to also provide "other" responses.

Thirty-two of the original sample of 200 institutions responded to the request to complete the survey. In order to collect further information about capstone courses from more colleges of education and departments of mathematics, the sample was increased by sending the survey to three email listservs (e.g., Project NExT). This second phase of solicitation altered the initial plan for random sampling; however, what was sacrificed in terms of the ability to make inferences was outweighed by the benefit of having a larger sample of courses. The final set of data collected from 73 universities was analyzed in Microsoft Excel using basic summary statistics.

The respondents represented a variety of institutions, as reflected in (Carnegie Classifications, 2011); this data is summarized in Table 1. Of the 73 responses, 42 (57.5%) reported having a mathematics content course, taken at the conclusion of a program of study

for pre-service secondary mathematics teachers, that satisfies at least one of the goals for a capstone course listed in (Loe & Rezak, 2006). That is, each of these 42 survey respondents indicated that their institution offered a course intended to provide at least one of the following:

1. bridges between upper-level mathematics courses,
2. connections to high school mathematics,
3. additional exposure to mathematics content in which students may be deficient, or
4. experiences communicating with and about mathematics.

Among the 42 respondents reporting capstone courses at their institution, one submitted details about two different courses, and two did not provide any additional information about their courses. Therefore, the final data represents 41 distinct capstone courses. As the survey defined a capstone course more broadly than the CBMS recommendation, the results reported below make a distinction between courses that have been labeled as CBMS and non-CBMS courses. For the purpose of analyses, a CBMS course was defined as one that specifically aligns with the CBMS recommendation (Loe & Rezak, 2006) of "connecting [students'] college mathematics courses with high school mathematics" (p. 8). Parsing the data in this way allowed examination of the differences among the capstone courses that align with the CBMS recommendation and the courses that do not.

Table 1

Summary of the sample

Carnegie Type	**All Responses**	**Capstone**	**Capstone & CBMS**
Bac/A&S: Baccalaureate Colleges--Arts & Sciences	12 (16.4%)	6 (14.3%)	0 (0%)
Bac/Assoc: Baccalaureate/Associate's Colleges	3 (4.1%)	1 (2.4%)	0 (0%)
Bac/Diverse: Baccalaureate Colleges--Diverse Fields	8 (11.0%)	7 (16.7%)	6 (23.1%)
Master's L: Master's Colleges and Universities (larger programs)*	24 (32.9%)	15 (35.7%)	10 (38.5%)
Master's M: Master's Colleges and Universities (medium programs)*	7 (9.6%)	5 (11.9%)	3 (11.5%)
Master's S: Master's Colleges and Universities (smaller programs)	4 (5.5%)	3 (7.1%)	2 (7.7%)
DRU: Doctoral/Research Universities	3 (4.1%)	0 (0%)	0 (0%)
RU/H: Research Universities (high research activity)	3 (4.1%)	3 (7.1%)	3 (11.5%)
RU/VH: Research Universities (very high research activity)	8 (11.0%)	2 (4.8%)	2 (7.7%)
Spec/Faith: Special Focus Institutions--Theological seminaries, Bible colleges, and other faith-related institutions	1 (1.4%)	0 (0%)	0 (0%)
TOTAL	73	42	26

* Each of these categories has one respondent that has a capstone but did not answer follow-up questions; it is unknown whether they align with the CBMS recommendation.

The data that allowed for creating the distinction between a CBMS and non-CBMS course were captured by a question about the purposes of the course. Table 2 lists six capstone course purposes and summarizes responses to this question; respondents were instructed to "check all that apply." Respondents who indicated that their institution's capstone course aligned with purpose (b) were classified here as CBMS courses; a non-CBMS course is one which aligns with at least one of the other purposes listed in Table 2, but does not align with purpose (b). Of the 41 capstone courses described by survey respondents, 26 were assigned this CBMS distinction.

Table 2
Purpose of the capstone (n=41)

Purpose of capstone is to provide:	**n**	**%**
a. bridges between upper-level mathematics courses, especially real analysis, abstract algebra, probability/statistics, and geometry	22	54%
b. an opportunity to explore connections between college mathematics and secondary school mathematics	26	63%
c. additional exposure to areas of mathematics in which they may be deficient	24	59%
d. research and writing in mathematics and with making oral presentations to their peers and instructors	33	80%
e. the opportunity to learn pedagogical principles for teaching secondary mathematics	9	22%
f. opportunities to become familiar with technology for teaching	9	22%
g. other	8	20%

Results

The data provide insight into three major aspects of the capstone courses: (1) Course Goals, (2) Logistics, and (3) Participants. First, we provide more depth and texture about the goals of capstone courses in the sample. Second, we describe the logistics of the courses including prerequisite coursework, which not only puts the capstone courses into the context of a broader program of study, it offers insight into available and applicable topics for inclusion in course curriculum. In this section we also look at the available resources that instructors draw upon when planning including textbook selection. Third, we examine the participants in these courses including both instructors and students. In this section we explore the population for whom capstone courses are designed and available as well as instructor background and freedom.

I. Course Goals

The CBMS vs. non-CBMS distinction was apparent in the responses to a question regarding the goals of the capstone courses. (See Table 3.) If the purpose defines the reason for creating such a course, the goals are specific statements that define the outcomes for the course. Goals (b) and (e) in Table 3 correspond to the CBMS recommendations and were, as might be expected, much more prevalent in the CBMS courses. The most common goal for both CBMS and non-CBMS courses was for students to develop a deeper understanding of mathematics. Survey respondents were given an opportunity to name goals that were not given in the survey list. Examples of additional goals for non-CBMS courses included student investigation of a substantial mathematics topic and learning advanced mathematics on their own, while an example of a goal included in a CBMS course was the expectation that students clearly write mathematics.

II. Logistics

Capstone course prerequisites. One expectation was that the capstone course, as defined in this survey, is typically intended to be taken at the conclusion of a program of study for pre-service secondary mathematics teachers. Therefore, the survey probed the prerequisites for these courses. (See Table 4.) Five responses stated only that advanced standing was required; these responses have been removed from this portion of the analysis. Calculus and Linear Algebra were the most commonly listed prerequisites. The one capstone course which did not include Calculus as a prerequisite required a mathematics course specifically for pre-service mathematics teachers and six additional units of unspecified mathematics.

Table 3
Goals of capstones

Goals		All	CBMS	non-CBMS
a.	Students are knowledgeable about the university mathematics content addressed in the course	23 (56%)	13 (50%)	10 (67%)
b.	Students take an in-depth look at some mathematical topics which are particularly important in secondary mathematics	23 (56%)	20 (77%)	3 (20%)
c.	Students know how to use a variety of teaching strategies when teaching mathematics	6 (15%)	6 (23%)	0 (0%)
d.	Students can (effectively) integrate technology into their future classrooms	10 (24%)	9 (35%)	1 (7%)
e.	Students connect appropriate college mathematics content to high school mathematics content and pedagogy	19 (46%)	18 (69%)	1 (7%)
f.	Students become aware of current topics and issues in secondary school mathematics	7 (17%)	6 (23%)	1 (7%)
g.	Students develop a deeper appreciation of mathematics	35 (85%)	21 (81%)	14 (93%)
h.	Students develop a personal philosophy to support the teaching of secondary mathematics	8 (20%)	7 (27%)	1 (7%)
i.	Other	8 (20%)	2 (8%)	6 (40%)
	n	41	26	15

Table 4
Prerequisites for the capstone

Course Name	All	CBMS	Non-CBMS
Calculus	35 (97%)	22 (96%)	13 (100%)
Linear Algebra	31 (86%)	18 (78%)	13 (100%)
Discrete Mathematics	6 (17%)	4 (17%)	2 (15%)
*Abstract Algebra	14 (39%)	9 (39%)	5 (38%)
Euclidean Geometry	13 (36%)	6 (26%)	7 (54%)
*Probability	9 (25%)	7 (30%)	2 (15%)
*Real Analysis	15 (42%)	12 (52%)	3 (23%)
*Calculus-Based Statistics	8 (22%)	7 (30%)	1 (8%)
Other	18 (50%)	11 (48%)	7 (54%)
Statistics with no Calculus prereq.	15 (42%)	7 (30%)	8 (62%)
*Non-Euclidean Geometry	19 (53%)	12 (52%)	7 (54%)
Combinatorics	14 (39%)	9 (39%)	5 (38%)
n	36	23	13

* Upper-division courses

Some distinctions between CBMS and non-CBMS courses were particularly salient. The CBMS capstone courses were twice as likely to have non-Euclidean (rather than Euclidean) geometry as a prerequisite. These two geometry courses were equally likely prerequisites among the non-CBMS courses. Calculus-based Statistics was more popular as a prerequisite among CBMS courses; eight of the nine non-CBMS courses which required statistics did not require it to be calculus-based. If Probability, Calculus-Based Statistics, Non-Euclidean Geometry, Abstract Algebra, and Real Analysis are counted as upper-division courses, then 31% of all capstone courses reported no upper division prerequisites. This rate was consistent among both CBMS and non-CBMS courses, though there is divergence when the quantity of upper division prerequisites is considered. Among the CBMS courses, 65% required two or fewer upper division prerequisites, while only 46% of non-CBMS courses required two or fewer.

Topics covered in capstone courses. We found variety in the content of the capstone courses. A survey question asked, "In the last semester that the course was taught, what mathematical or pedagogical topics were examined?" Table 5 shows counts for the categories

of responses to this question. As compared with the non-CBMS courses, the CBMS courses included more secondary mathematics topics and pedagogical concerns. All of the non-CBMS courses addressed advanced mathematical topics.

Table 5

Categories of topics covered

Topic	All	CBMS	Non-CBMS
Deeper look at secondary mathematics	11 (33.3%)	11 (52.3%)	0 (0%)
Advanced mathematical topics	22 (66.7%)	10 (47.6%)	12 (100%)
History of mathematics	7 (21.2%)	4 (19.0%)	3 (25%)
Pedagogical concerns	6 (18.2%)	6 (28.6%)	0 (0%)
n	33	21	12

Capstone course resources. The resources used to develop the courses are summarized in Table 6. The development of CBMS courses was, to a greater extent, guided by national organizations and recommendations, as well as by educational organization standards. Four courses (three CBMS) were developed in consultation with education departments; survey respondents also listed other departments consulted, such as communications (CBMS) and science departments (non-CBMS).

Table 6

Resources used to develop capstone courses

Resources used to develop course	All	CBMS	non-CBMS
National guidelines	13 (31.7%)	11 (42.3%)	2 (13.3%)
Common Core State Standards	9 (22.%)	9 (34.6%)	0 (0%)
National Council of Teachers of Mathematics	17 (41.5%)	17 (65.4%)	0 (0%)
Conference Board of the Mathematical Sciences	11 (26.8%)	8 (30.8%)	3 (20.%)
Mathematical Association of America	22 (53.7%)	14 (53.8%)	8 (53.3%)
National Mathematics Advisory Board Recommendations	6 (14.6%)	4 (15.4%)	2 (13.3%)
Collaboration with other departments on campus	8 (19.5%)	6 (23.1%)	2 (13.3%)
Collaboration with other universities	5 (12.2%)	4 (15.4%)	1 (6.7%)
n	41	26	15

Among the 31 responses to questions about course materials, 18 different books were listed as course textbooks, 13 courses used materials from more than one outside source, and at least four used materials primarily developed internally. Among the many texts listed, only three were listed as a textbook for three or more capstone courses:

- *Mathematical connections: A capstone course*. Conway, J. (2010) – 3 courses
- *Mathematics for high school teachers: An advanced perspective.* Usiskin, Peressini, & Marchisotto, & Stanley (2002) – 7 courses
- *The mathematics that every secondary school math teacher needs to know.* Sultan & Artzt (2010) – 3 courses

Likewise, a wide variety of classroom technologies were used in the capstone courses, the most commonly used tools being Dynamic Geometry Software (e.g., Geometer's Sketchpad), graphing calculators, and Microsoft Excel. Of 39 respondents on this topic, only two reported to not use any technology in the course and both were non-CBMS courses. There was not a pronounced difference between CBMS and non-CBMS courses other than in the use of Excel, which was used exclusively in 16 CBMS courses.

III. Participants

Capstone course students. Six capstone courses, all of which were designated as CBMS courses, were described as being required specifically for pre-service mathematics teachers. In the non-CBMS courses, all of the students who enrolled in the courses were mathematics majors. At most schools (both CBMS and non-CBMS), students intending to be mathematics teachers did not exclusively populate the capstone courses. Indeed, only six capstone courses (all CBMS) reported that they were exclusively for students seeking teaching licensure. Two of the non-CBMS courses did not include any category of students seeking licensure. Table 7 lists the percentages of capstone courses in our sample that included various categories of students.

Table 7

Students to whom the capstone is available

Who takes the course?	All	CBMS	non-CBMS
Alternate licensure students post-baccalaureate	9 (22%)	8 (31%)	1 (7%)
Graduate students	4 (10%)	3 (12%)	1 (7%)
Undergraduate math majors	33 (80%)	18 (69%)	15 (100%)
Undergraduate math majors pursuing teaching licensure	34 (83%)	22 (85%)	12 (80%)
Undergraduate mathematics education majors pursuing teaching licensure	24 (59%)	17 (65%)	7 (47%)
Undergraduate math minors	14 (34%)	8 (31%)	6 (40%)
Undergraduate math minors pursuing licensure	11 (27%)	8 (31%)	3 (20%)
n	41	26	15

Capstone course instructors. Survey respondents were asked to describe the academic background of the instructor who has most often taught the course in the past five years and were welcomed to select multiple options. Table 8 summarizes the results. At least 14 out of 15 non-CBMS course instructors had backgrounds in mathematics; the fifteenth capstone course was reported to be conducted with individual instructors paired with students, however no specifics were provided regarding the backgrounds of those instructors. One CBMS capstone course was co-taught by a mathematician and mathematics educator. Only four instructors, all of whom teach CBMS capstones, were reported to exclusively have a mathematics education background.

Table 8

Instructor backgrounds

Instructor Background	All	CBMS	non-CBMS
Mathematics Only	25 (61.0%)	13 (50.0%)	12 (80.0%)
Mathematics Education Only	4 (9.8%)	4 (15.4%)	0 (0%)
Both Mathematics & Mathematics Educ.	10 (24.4%)	8 (30.8%)	2 (13.3%)
Neither	2 (4.9%)	1[1] (3.8%)	1[2] (6.7%)
n	41	26	15

1. Indicated Computer Science background
2. Students matched one-on-one with faculty members (background non-specified)

Survey respondents were asked to comment on the level of instructor freedom in choosing the topics examined in the capstone course. With one exception, all respondents reported having at least some freedom in selecting courses with 33 of 41 capstone courses (80.5%) selecting the following: "A lot - There are limited guidelines or recommendations for teaching this course, so instructors get to choose the materials they want to use." The rate was consistent across CBMS and non-CBMS courses. Only one capstone course (CBMS) was reported to have no instructor freedom because a course coordinator chooses the materials. The survey also investigated instructor freedom in how the course was taught or structured. With no exceptions, all respondents reported having either no departmental recommendations

for how the course would be taught (25/41) or some non-mandated recommendations (15/41), with one non-response to the question.

Discussion

Ten years after the initial CBMS recommendation to include six credit hours of coursework to connect college mathematics courses with high school mathematics, courses that align with this recommendation seem not to be widespread. Only 26 of the 73 institutions that responded to the survey had at least one course goal that aligned with the CBMS recommendation. Furthermore, assuming that six hours of coursework would span more than one semester/quarter, only 7 of the 26 CBMS capstone courses in the sample likely satisfy this requirement. Looking beyond the CBMS recommendation, 16 institutions in our sample provide a capstone experience (not aligned with the CBMS recommendation) for pre-service secondary mathematics teachers.

A distinction between CBMS vs. non-CBMS aligned courses was developed based on the stated purposes of the capstone course. A CBMS capstone course has the (not necessarily sole) purpose to connect college and high school mathematics, as recommended by the CBMS. The survey, however, used a broader definition of "capstone" and included courses that fostered connections between college-level courses, provided exposure to additional mathematics content, and/or engaged students in communicating with or about mathematics. Indeed, most capstone courses reported in the survey addressed many of these and other goals and served multiple purposes. The survey data indicate diversity across many characteristics of the courses that respondents identified as capstones.

Despite this diversity, some general features are shared by most capstone courses in our sample. All 41 capstone courses were completed by pre-service secondary mathematics teachers at the end of their undergraduate experience; however, only 6 of the 41 capstone courses were taken exclusively by pre-service secondary teachers. This lack of exclusivity may be connected to the CBMS observation in (CBMS, 2012) that courses for future teachers may be difficult to implement in institutions that serve a small number of pre-service mathematics teachers. The survey, however, did not reveal this level of detail. Additionally, in general, instructors reported a large amount of freedom in choosing the content and instructional style for their courses. This freedom is also reflected in the wide variety of assessment devices and resources used. It is possible that this is a byproduct of the capstone being a relatively new type of course. Indeed, a defining feature of the current state of capstone courses is the variety of forms.

Within this variety, there are notable differences between CBMS and non-CBMS courses. CBMS capstones are more likely to be developed in consultation with national guidelines from mathematics and educational organizations. They are also more likely to be taught by someone with a mathematics education background. Though most (69%) capstone courses required upper division courses as pre-requisites, there were some differences in the type of courses required by CBMS courses, particularly in the areas of geometry and statistics and in the quantity of upper division prerequisites (more were required by non-CBMS capstones).

Given these differences between the two categories of capstones investigated here, along with their differences in purpose, it would be tempting to characterize the differences between CBMS and non-CBMS courses as being signs of different programmatic foci. Specifically, perhaps the CBMS courses are located in programs more focused on teacher preparation. However, there are also signs to indicate that this may not be the case. Notably, CBMS courses are more likely to include a calculus-based statistics course (instead of a lower-level statistics course) as a prerequisite and are less likely to have a Euclidean geometry prerequisite. That is, the prerequisite coursework in programs with CBMS capstones may be less amenable to making connections to high school content throughout the

undergraduate program. Indeed, a capstone which focuses on high school connections may be more of a necessity in departments with prerequisite coursework which does not support this.

It has been just over a decade since the CBMS first recommended capstone courses for pre-service secondary mathematics teachers. In February 2012, the CBMS released a draft of an update to their 2001 recommendations for the mathematics education of teachers (CMBS, 2012). In this update, the CBMS has strengthened the specific recommendation that pre-service secondary mathematics teachers interact with high school mathematics content at a deeper level. In particular, rather than suggesting a specific course such as a capstone, the CBMS now recommends that pre-service secondary mathematics teachers complete the equivalent of a mathematics major "that includes three courses with a primary focus on high school mathematics from an advanced viewpoint" (p. 7).

Though the study described in this article was more widely focused than trying to measure the impact of the initial CBMS recommendation (CBMS, 2001), the survey results give some indication of how new recommendations could be interpreted and implemented. While it may be a significant challenge for institutions to make the kind of programmatic changes involved in the new recommendations, there seems to be flexibility in the structure of existing capstone courses that may facilitate that work. On the other hand, it is clear from our survey that the initial recommendations were not universally interpreted or even understood. It will be important going forth to not only continue to document the design of courses that meet the recommendations, but also to use our reports of these courses to engage in a broader conversation about how connections can be made between advanced mathematical coursework and the mathematical knowledge needed for secondary teaching as well as how these connections impact pre-service secondary mathematics teachers in their degree programs and as they enter their classrooms.

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