The Secondary–Tertiary Transition in Mathematics: A Multifaceted Issue

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Introduction

The discontinuities between school and university are plentiful, which is a major concern due to the growing need for a college education without regard for student preparation in secondary schools. As B. R. Clark (1960) wrote:

In American higher education the aspirations of the multitude are encouraged by "open-door" admission to public-supported colleges. The means of moving upward in status and maintaining high status now include some years in college, and a college education is a prerequisite of the better positions in business and the professions. The trend is toward an even tighter connection between higher education and higher occupations, as increased specialization and professionalization insure that more persons will need more preparations. The high-school graduate, seeing college as essential to success, will seek to enter some college, regardless of his record in high school. (p.570)

Despite the words of B. R. Clark being over fifty years old, they still ring true today. This concern is further exacerbated by the dismal 6-year U.S. four-year college and university graduation rates—around 59% for first-time, full-time students starting in 2007 and graduating by 2013 (National Center for Education Statistics, 2015).

The transition from secondary to post-secondary education is certainly a contributing factor to these issues. Beach defines transition as "a developmental change in the relation between an individual and one or more social activities. ... Transitions are consequential when ... the eventual outcome changes one's sense of self and social positioning" (2003, p. 114), and there exists a relative glut of recent research on the general issue of the transition from secondary school to university. That said, this transition is not considered a new problem; DeGuzmán, Hodgson, Robert, and Villani identify reports on this topic as far back as 1967 (1998). As might be expected, there is a great diversity in perspectives as to the cause and necessity of the gap that currently exists. In this examination of the literature, I focus on the causes and categories of problems associated with this transition, the two dominant frameworks that guide analysis of this transition (especially as they apply to the study of mathematics) as well as discuss ways in which these analyses are limited, and potential ways to mitigate the identified transition problems.

Method of Selecting Articles

Articles were first identified by searching relevant databases, namely ERIC, JSTOR, MathSciNet, EBSCOhost, and Google Scholar. A combination of descriptors and descriptor roots were used (alphabetically: gap, high school, higher ed*, math*, secondary*, school, tertiary, transition*, university) to collect articles. Each item was then subjected to an abstract analysis and, subsequently, a thorough reading with key points coded.

Studies were selected for inclusion if they met the following criteria:

1. Studies were published in peer-reviewed journals, proceedings of peer-reviewed conferences, or in any medium so long as it has been cited no fewer than 10 times, as identified in Google Scholar (so as to imply significance to the field of study despite its origins).

2. Studies were published in English or translated into English.

3. The primary focus of the studies was the transition to mathematics at the post-secondary level. Studies were considered, although none were eventually included in this review, if their focus was on the phenomenology of the transition to university, irrespective of subject.

4. Given the pace of changing policy regarding secondary education, studies were published after the year 2006, unless there was significant evidence supporting inclusion of the study (i.e.: a seminal work).

This process reduced the collection of articles to a total of 12 items.

In the spirit of completeness, additional articles were identified from discussions with other researchers. From each of these articles, a citation analysis was conducted, moving both forward and backward in time (i.e.: works cited in the identified articles as well as works citing the identified articles), with the assistance of Google Scholar. The items selected by this method were subjected to the same rigor for selection that the database-identified items were, which produced an additional 18 items, for a total of 30 items to be used in this literature review.

These articles were then subjected to a close read and open coding. The resulting codes form structure of this review.

Types of Difficulties in the Transition to Tertiary Mathematics

In the discussion of the secondary–tertiary transition, it would be remiss to not enter into a discussion of the difficulties that the transition presents to students. The work of DeGuzmán et al. (1998) is widely accepted as foundational in establishing broad, yet distinct, categories for these difficulties. As such, I have adopted their category names verbatim for the subsections and discussion presented below.

Epistemological and Cognitive Difficulties

These difficulties originate from the conceptual leap that corresponds with the transition to university mathematics (DeGuzmán et al., 1998). It is important to note that these difficulties are often misrepresented by students as the content at university being merely "more difficult" than in school (DeGuzmán et al., 1998; Hernandez-Martinez et al., 2011). Other student misconceptions that are possibly indicative of epistemological and cognitive difficulties are: the nature of mathematics ("[m]athematics is figuring out problems involving numbers"), learning approaches ("...it's only worth studying the mathematics that I know will be examined"), and instructor and course criticisms ("[t]he workload...is too heavy") (Crawford, Gordon, Nicholas, & Prosser, 1998, p. 460). In reality, the topics in post-secondary mathematics are often different and, even when they are not, they are explored with increased depth (both procedural and conceptual). High-achieving secondary students are often quite adept at performing algorithms despite lacking understanding of the concepts that govern them. These students may experience substantial difficulty in transition due to their systemically validated belief that their surface learning constitutes mathematical talent or ability (Crawford et al., 1998; DeGuzmán et al., 1998; Kajander & Lovric, 2005). Since they have been trained to reproduce mathematical information, these students often have difficulty becoming autonomous mathematical learners (Crawford et al., 1998; DeGuzmán et al., 1998). Students are encouraged to adopt these rote, surface-learning practices by the typical assessment given in secondary school, which emphasizes the ability to accurately reproduce mathematical information over the ability to reason mathematically (Taylor, 2008; Thomas & Klymchuk, 2012; Wood, 2001).

Sociological and Cultural Difficulties

While classes in secondary schools are typically modest in size, by comparison, they are often dwarfed by the size of an introductory-subject being taught at the tertiary level. This shift from being able to know most of the individuals in one's class to being an anonymous face in a sea of students can be quite the culture-shock for students in transition (Taylor, 2008). Exacerbating the stresses of the change in peer group size is the fact that peer groups at university are often poorly defined and often in flux, with students at different points in their academic progression and students with different academic interests are often thrust into the same course. This fact alone makes forming a sense of community within the classroom an elephantine challenge (DeGuzmán et al., 1998). Further, communication becomes an ever-present issue. Since lecturers, often professional researchers, may have more responsibilities outside of their classrooms than their teacher counterparts which creates an artificial barrier between the lecturer and the students. Teaching assistants are helpful, but students may not have unfettered access to them since most teaching assistants are graduate students with limited numbers of hours and myriad demands outside of their work assignment as well. Even when the directions and requests of the instructor are made explicit, they are often misinterpreted by students who are less likely to request clarification or to even participate due to the unfamiliar anonymity of the tertiary class (Kouvela, 2015).

Didactic Difficulties

Many students arrive at university not knowing "how to take notes during a lecture, how to read a textbook, how to plan for the study of a topic, which questions to ask themselves before they get asked by the teacher" (DeGuzmán et al., 1998, pp. 756–757). That is, the students enter into tertiary mathematics, unable to teach themselves. Further, a number of attitudes and beliefs affect teacher efficacy in universities. DeGuzmán et al. provide the following list of some such attitudes and beliefs:

- A lack in pedagogical and didactical abilities—the belief that all one needs in order to teach mathematics is to know and understand the subject.
- A lack of positive role models—new instructors often identify role models who are gifted researchers, but rarely does one find (or is directed to) one that is a gifted educator.
- A disregard for the importance of methodology—not sharing with students how mathematics is really done by mathematicians.
- A lack of innovation—university classrooms are still predominantly delivered exclusively via 'chalk-and-talk' lectures.
- Haphazard course design—university instructors may not give much, if any, thought to the preparation and pace of their curriculum, and even when such consideration is given, it is rarely shared with students.
- A lack of feedback procedures—lectures often operate as monologues with little to no feedback on teaching and learning from the students to the instructor.
- A lack of assessment skills—there exists a prevalence of the written exam as assessment (most distressing of which is any form that requires no human grader) with little to no consideration for possibly stronger alternate assessment strategies. (1998)

Approaches in the Literature

There are a number of beliefs about the nature of transition from school to university mathematics. The vast majority of the research acknowledges that the transition from secondary to tertiary school involves a number of changes associated with the difficulties described above. These changes include the mathematical content, the learning environment, the cognition required, and social adjustments (Hong et al., 2009; Wood, 2001). The way that the literature approaches and ranks, by importance, these changes, by-and-large, fall into one of two frameworks: the transition is qualitatively dependent on coursework and preparation (content specific transition) and the transition is a culturally constructed phenomenon (transition as a rite of passage).

Content Specific Transition Perspective

This is the belief that the secondary–tertiary transition is primarily an issue of academic preparedness and looks at the cognition required in specific courses and discusses, in-depth, the transition, as Tall (1997) puts it, as one from elementary to formal mathematics. The literature that adopts this framework, either explicitly or implicitly, attests that the one of the primary problems that students face in transition is epistemological and cognitive difficulties (DeGuzmán et al., 1998).

At school the accent is on computations and manipulation of symbols to "get an answer", using graphs to provide imagery to suggest properties. At university there is a bifurcation between technical mathematics that follows with style (with increasingly sophisticated techniques) and formal mathematics. (Tall 1997, p.1)

It is precisely this avenue of exploration of the problems students face when transitioning to formal mathematics that would eventually lead Tall to develop his theory of the Three Worlds of Advanced Mathematical Thinking (see Tall (2004)). This perspective often considers the secondary–tertiary transition as occurring starting in the last two years of secondary school and ending only when students successfully manage to move to advanced mathematical thinking; typically, this is arbitrarily set at the end of the second year of post-secondary training (see Dreyfus (1991) for a good description of what is meant here by advanced mathematical thinking as well as the chain of processes that develop it) (Tall, 1997, 2008).

There exist a great many pieces of research that turn an analytical eye toward the teaching and learning of many subjects found in lower-level undergraduate mathematics. As such, it is not appropriate to try to treat these subjects as in isolation in this review–doing so would be quite long-winded and away from the intended focus of this paper.

It is, however, important to notice that there is commonality between many of these subjects. In Analysis, "in secondary schools the focus is on the practical-theoretical blocks of concrete analysis, while at university level the focus is more on complex praxeologies of concrete analysis and on abstract analysis" (Thomas et al., 2012, p. 95). In Abstract Algebra, "students' overall problematic experience of the transition... is characterised by the strong interplay between strictly conceptual matters,... affective issues and those that are germane to the wider study skills and coping strategies that students are at university with" (Thomas et al., 2012, p. 101). In Linear Algebra, "one of the challenges of the transition from secondary algebra to university linear algebra is that the formalism obstacle appears when students work with expressions losing sight of the mathematical object that the symbols represent" (Thomas et al., 2012, p. 102). On the nature of equations, "[i]t has been recognised that many student perspectives on equations and their use of the equals sign have not mirrored those that mathematicians would like to see in tertiary students" (Godfrey & Thomas, 2008, p. 71). Each of these quotes discusses the same problem: secondary schools are not producing graduates that have the prerequisite skills in order to mitigate the epistemological and cognitive difficulties associated with transition.

Perhaps it is because of the working nature between students and university lecturers but when asked about the difficulties that their students were experiencing, most lecturers cited epistemological and cognitive difficulties, which may explain the proliferation of publications written from this perspective (Gruenwald, Klymchuk, & Jovanoski, 2004; Hong et al., 2009).

Rite of Passage Perspective

M. Clark and Lovric (2008, 2009) posit that the secondary–tertiary transition can and perhaps should be viewed from the anthropological lens as a Rite of Passage. Rites of passage are events that move an individual from a state of crisis to a return to normalcy and are separated into three distinct phases: separation, liminal, and incorporation. In the context of the secondary–tertiary mathematics transition for traditional first-year undergraduates, the separation phase occurs in that they are often physically separated from their home, family, and friends. They must also learn to shed their previous roles, thought processes, and expectations as they learn to function in their new, post-secondary setting (M. Clark & Lovric, 2008). The separation phase begins while students are still in their high school and have begun anticipating the life change ahead of them. (M. Clark & Lovric, 2009). It is at this point that the verbiage of the articles begin to differ than the explicit framework that M. Clark and Lovric have put forth. In M. Clark and Lovric (2009), it is asserted that the liminal phase occurs between the end of high school and the start of the first year at university and the incorporation phase includes roughly the first year of university. Although few authors openly invoke this framework, contextually most agree that the liminal phase does not end at the beginning of life as a university student. Rather, a more appropriate timeline, in relation to mathematics, might list the separation phase as the final year of secondary school, liminal as the time between graduation and the first several experiences with formal mathematics, and the incorporation phase may only occur by the end of undergraduate study. Of course, these timelines are of little value without agreement on the milestones of each phase. I contend that if the goal of mathematics training is, in the words of Dreyfus, to "bring our students' mathematical thinking as close as possible to that of a working mathematician's" (1991, p. 41), then we must consider transition the process affecting our students until they achieve Tall's advanced mathematical thinking. This clearly makes the transition much more difficult to study as it removes the clear temporal boundaries from the rite and forces us to consider much more profoundly the cognition, metacognition, and self-efficacy our students–which are not transitioning all at the same rates. Ironically, M. Clark and Lovric (2009), which describes their timeline for transition, is the source that most openly disputes the existence of a potential set timeline:

Thus, a success in transition can tentatively be defined as accomplishing most of: individual is comfortable in her/his new role as a university student, she/he is able to achieve and work towards their goals, she/he shows good academic progress, she/he has support (both academic and otherwise), and can access it when needed, she/he enjoys mathematics courses, etc. However, students' individual goals and expectations of tertiary education are so broad that, by itself, would render futile any attempt at defining what success in transition really is. (p.759)

The most notable difference between this perspective and the content-specific perspective presented above is that when viewed as a rite of passage, attempts to remove the difficulties of transition from secondary to tertiary mathematics are likely to be more harmful to the overall development of the students.

Due to the complications in determining which phase students may be in during their transition, I have broadly considered all publications that consider such sociological and cultural difficulties as the primary source of transition distress. The literature that adopts this framework, either explicitly or implicitly, attests that the one of the primary problems that students face in transition is sociological and cultural difficulties (DeGuzmán et al., 1998). Even with this broad inclusion, there are notably fewer articles that attempt to make use of the framework of M. Clark and Lovric (2008, 2009), which is perhaps expected given the novelty of the framework, but the framework is interesting enough to warrant close inspection, especially given its sharp contrast to the content-specific framework.

There are numerous culture differences between school and university, which is part of the reason why some researchers are suggesting that any further refining of the cut-scores in mathematics required for entry into certain classes or even certain majors are likely to not improve student outcomes (Barton, Goos, Wood, & Miskovich, 2012). That is, there must be something more to the transition than merely readiness, and that other thing must have sufficient weight to overcome unlimited academic preparation.

Hernandez-Martinez et al. (2011) found that despite the abundance of anecdotal evidence and research suggesting that transition is a problem to be overcome, students often view the change with a sense of excited optimism and are quite excited to take on the challenges that the new situation, expectations, and environment bring with them. Further, “the more severe the troubles, the more life-affirming the transition is as a record of successful growing up, in the students’ narratives” (Hernandez-Martinez et al., 2011, pp. 127–128).

A Complicated Issue

Content-specific framework views the transition as being inherently married to the course in which the student is engaged, thus the secondary–tertiary transition for a high achieving student that is taking linear algebra their first or second year is significantly different than a student taking calculus, whereas the rite of passage framework suggests that although variances occur between students, the essence of the transition transcends coursework distinctions and is influenced more by the differences in cultures (student and professional) at school and at university. Further, the content-specific framework often seeks to ‘narrow the gap’ between secondary and tertiary mathematics, while the rite of passage framework suggests that these attempts are inherently detrimental to student transition and that the pain of transition is necessary to the rite of passage itself. Of course, it is much more comfortable for mathematicians to focus on content and leave sociological and cultural difficulties to other academics to study, but doing so only reveals to us part of the story. Important lessons can be gleaned from careful examination of both the cultures on either end of the secondary–tertiary transition as well as from the content-specific skills that students have or lack entering into higher education. It is shortsighted to assume that narrowing the gap between school and university can, by itself, adequately mitigate or even remove the transition problems that many students face when entering the tertiary environment. On the other hand, the evidence is too substantial to pretend as though preparation (in school) and reasonable expectations (at university) do not have very significant impacts on this transition, as measured in performance, retention, and eventual graduation rates with respect to mathematics (see: Barnett, Sonnert, and Sadler (2014), James, Monelle, and Williams (2008), Jennings (2009), Rylands and Coady (2009)). As such, the reasonable perspective that it is a combination of both coursework (in choice, preparedness, and nature) and culture (of school, university, society, and the academy) that governs the transition process.

Recommendations

A great many of the readings used to compose this review end their work with suggestions for improving the current system. Some are in direct opposition to each other, such as the implication of Wood (2001) that universities should emulate things that work in secondary education, which goes against the suggestions put forth by M. Clark and Lovric (2008) who propose that by being different that secondary classrooms, universities are promoting changes in students that will help them be successful in formal mathematics. There are a number of areas, however, that there is general agreement between the two perspectives. Several recommendations are provided below, in no particular order.

Bridging Courses

Bridging courses in this context refers to those courses that occur after the formal end of high school but before the formal course of study at university. These courses may take the role of non-credit refresher or even remediation classes or may be for-credit (as elective) courses that serve as prerequisites to the first mathematics course required by a degree program. These courses should have targeted goals to match targeted populations. For instance, bridging courses that cater to fields that use mathematics as a service course should have emphasis on deep problem solving and procedural competence, while bridging courses that cater to fields that require formal mathematics should introduce the vocabulary, structure, and presentation of such formal mathematics–to include deductive reasoning. By separating these cohorts, universities will be better able to provide meaningful experiences for students while promoting those skills necessary for advancement in their chosen academic paths. These bridging courses should be required very early in students' course of study since "skills and attitudes [developed] in the first year can lead to more effective learning in later years" (Wood, 2001, p. 91). These courses should use non-traditional and non-contrived tasks, as such tasks may promote a transition from surface learning to deep conceptual learning (Breen, O'Shea, & Pfeiffer, 2013).

Student Support Systems

It is clear that strong student support systems are needed to assist in transition. These supports may come as individualized assistance, group tutorial sessions, workshops, reviews, self-study guides, etc. (Wood, 2001). Student help centers are highly visible outlets to provide such support (DeGuzmán et al., 1998). It is important for not just paid tutors and graduate students to provide this assistance–faculty must as well. By requiring faculty to offer regular assistance, outside and beyond "office hours," opens up communication channels with students and can begin to alleviate some of the stress caused by the change in social environments.

Open and Candid Discourse

The most common suggestion found in the literature is an increase in communication.

Typically this is described as coordination between secondary school teachers and post-secondary lecturers, but occasionally also between professionals and students. I believe whole-heartedly that the latter of these two is perhaps the more beneficial of the two.

Between Educators and Students

"Rites of passage involve situations that are clearly defined and transparent to everyone involved, so, while still in high school, students should be told (directly and in detail) about their future life as university students" (M. Clark & Lovric, 2008, p. 30). Even if one does not believe that transition should be viewed as a rite of passage, with all of the implications implicit to that perspective, it is hard to believe that being candid with students about the ways in which their lives and their study will change could be detrimental.

Between Professionals

Barton, Clark, and Sheryn (2010) describes the outcomes of a meeting between university lecturers and secondary teachers. Among the outcomes are an agreed upon need for "the means and opportunity to continue the conversation about mathematics between teachers and university lecturers" and "better information about mathematics requirements at university to people who help students make choices within school" (2010, p. 25). Di Martino and Maracci (2009) describes the results of two university preparatory courses that allowed lecturers and teachers to collaborate. Their intervention in secondary school allowed them to share materials and ideas with teachers, providing a rich dialogue between the educators. Further, lecturers often lack knowledge of what is going in in secondary schools (Gruenwald et al., 2004). This must be rectified if there is any hope of coordinating efforts to ease transition for students. One convenient place to begin these discussions is between mathematicians and pre-service secondary mathematics teacher educators within individual institutions. In this way lecturers may gain a better understanding of the realities of secondary mathematics classes as well as obtain some pedagogical training for them to exercise in their own classes.

Rigor and Expectations

Schoenfeld (1994) provides a telling vignette about when he created a problem-solving course, but his department chair did not want to allow mathematics students to receive credit for the course because it lacked what he perceived to be "content." We must rethink the desired outcomes of especially our bridging and introductory courses. It is well established that lecturers perceive that their students are entering tertiary mathematics with little more than a poorly organized catalog of procedures and a disturbing lack of conceptual understanding. Should our idea of content be fixated on large lists of reproducible procedures of little developmental value or on smaller lists of concepts of which our students have deep, meaningful, and flexible understandings? "The danger in this kind of 'content inventory' point of view comes from what it leaves out: the critically important point that mathematical thinking consists of a lot more than knowing facts, theorems, techniques, etc." (Schoenfeld, 1994, p. 57). Our courses need to reflect this reality as well.

Community

Lacking in the majority of the literature is the need to establish a sense of community in transition. Rites of passage occur with cohorts of uninitiated moving through together. Although the realities of university make this difficult, it would be beneficial to encourage this behavior in tertiary mathematics, especially in first year and bridging courses. Beyond this, since rites of passage affect the whole community (M. Clark & Lovric, 2008), the reasonable analog in academia would be more mentorship by faculty members, graduate students, and more advanced peer students. Students should feel not just welcome but also involved.

Conclusion

In this review we have explored the nature of transition problems through the categorization of DeGuzmán et al. (1998), very briefly explored two dominant perspectives in the research and discussion of the secondary–tertiary transition, and offered suggestions to mitigate transition difficulties that accommodate both perspectives. Through the reading of the current literature a few questions are answered, although a great many more are made apparent. The one thing that the research does clearly illustrate is that the transition from high school to university is multifaceted and that atomistic approaches to minimize the gap between secondary and tertiary mathematics are likely to produce inadequate results–a holistic approach is required.

Although it is apparent that the study of the secondary–tertiary transition is one that has experienced tremendous research interest in the past decade, there is still much work to be done. Of the articles consulted for this review, the overwhelming majority of the research has come from Australasia, and a significant number of recent publications have been reviews of existing literature themselves. Other countries such as Ireland, the United Kingdom, the United States of America, and Canada are represented in the reading by no more than two articles each. This constitutes a glaring hole in the literature. Without in-depth comparisons of the secondary and tertiary mathematics standards and norms (not to mention the cultural norms surrounding education itself), one must be very cautious to accept that the findings in, for instance, Auckland, New Zealand have parallels in Boston, USA. I cannot strongly enough recommend such a study as a course for future research.

Also, the frameworks with which the epistemological and cognitive difficulties have been analyzed are quite robust and frameworks for examination of the sociological and cultural difficulties are being refined. However, there is currently little effort to build frameworks with which the didactical difficulties can be studied. Such work is far from trivial, and is necessary to develop the rich body of research needed to establish any semblance of 'best teaching practices' in university mathematics. It is unclear how much, or even if any, of the results from similar examinations in secondary mathematics education can be applied to the tertiary mathematics classroom. Further research is also needed to address these issues.

Lastly, there is little research as to the interplay of the three categories of transition difficulty. Can excellent university lecturers help students overcome their epistemological difficulties? Do social and cultural difficulties mediate didactical difficulties? Questions such as these are entirely unanswered and provide yet more avenues for future research. Research into the secondary–tertiary transition is an exciting new field of research that marries together the interests of stakeholders in both secondary and tertiary mathematics education. As such, it would be imprudent to categorize the field as a secondary mathematics education or mathematics (specifically research in undergraduate mathematics education) topic for the sake of research–it is indeed a hybrid of the two. As such, research in this field carries the opportunity to bring together professional mathematicians and pre-service teacher educators and begin the process of implementing the recommendations provided above.

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