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A Citation Analysis of the Theoretical Model for Secondary-Tertiary Transition in Mathematics

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Introduction

In this conceptual essay, a citation analysis of the Theoretical Model for the Secondary-Tertiary Transition in Mathematics developed by Clark and Lovric [1],[2] is completed. The theoretical model proposes that the secondary-tertiary transition in mathematics is a rite of passage [1],[2]. During the transition, students may struggle due to differences in high school and college mathematics [1],[2]. Because of this struggle, mathematics is commonly characterized as a gatekeeper to Science, Technology, Engineering, and Mathematics (STEM) degrees [3]. Therefore, for mathematics-heavy STEM majors, such as engineering, mathematics course requirements could inhibit STEM degree completion. By better understanding the secondary-tertiary transition in mathematics, student accessibility to college mathematics could improve.

Examination of the model's utilization in empirical research may provide information about how researchers interpret and draw upon of the publications, as well as the nature of the influence of the theoretical model [4], [5], [6]. The peer-reviewed publications will be analyzed for their purpose and relation to engineering education. The nature of the citation instances will be analyzed for their primary purpose in empirical research. This analysis will explore the interpretation and context of the theoretical model and its relations to mathematics and engineering education. Salient findings from the citation analysis may focus future research concerning the transition from high school mathematics to college mathematics.

Summary of theoretical framework for secondary-tertiary transition in mathematics

Because there was not an existing theoretical model for the secondary-tertiary transition in mathematics, Clark and Lovric developed one using the anthropological concept known as the rite of passage [1]. In 1960, Van Gennep [7] described a rite of passage as personal events where routines are changed during the transition to a new routine. Clark and Lovric [1] mapped three anthropological stages - separation, liminal, and incorporation - onto the secondary-tertiary transition in mathematics. The separation phase occurs when the student is in high school and anticipating college attendance [1]. The liminal phase is when the student has finished high school and awaiting the beginning of college, and this phase continues into the beginning college. The final phase, incorporation, is when the student has integrated into college life, and this phase is complete by the end of the first year of college. When these phases are mapped onto the secondary and tertiary transition in mathematics, several inconsistencies between secondary and tertiary levels are apparent. In 2009, Clark & Lovric, [2] published an enhanced version of the model. The 2009 article [2] included the concept of cognitive conflict where new knowledge is incompatible with prior knowledge. They also elaborated on the discontinuities between secondary and tertiary mathematics.

According to the Theoretical Model for Secondary-Tertiary Transition in Mathematics [1],[2], high school mathematics content and pedagogy may differ from college mathematics. Specifically, between high school and college mathematics, there may be a cognitive conflict where the tertiary mathematics is incompatible with the secondary mathematics [1],[2]. It is characterized as going from a surface level learning of mathematics to a deep understanding of mathematics [1],[2]. The model describes a discontinuity between the instruction and mathematics strategies in high school and university mathematics, while acknowledging poor communication between two [1],[2]. Clark and Lovric describe a Synthetic Model where students use a mixture of mathematics facts and their beliefs about mathematics to make conjectures, which leads to mathematics misconceptions making the transition to tertiary mathematics more difficult [2].

Students' responses to the transition in their mathematics attitudes, beliefs, motivation, and emotions are a part of their transition [1,2]. Clark and Lovric [2] describe transitioning from secondary to tertiary mathematics as a crisis which evokes strong emotions influencing their actions. There are stressful and confusing aspects encountered during the transition, but in the incorporation phase, students feel more like members of a new community. To make this transition, students will construct ways to independently meet all the demands, expectations, and responsibilities required by university mathematics with a new college community for support [1],[2].

The factor of time is prevalent throughout the model. For example, the transition from secondary to tertiary mathematics takes time. [1],[2]. If the student was accelerated in secondary mathematics, it's possible the student did not have the time to obtain a deep understanding of mathematics [1]. Learning loss experienced in the liminal phase, which occurs between high school and college, is a factor [1]. Once the student is in college, they must manage their time for mathematics study and practice [1], and it takes time for the student to build their new community [2].

Methodology

The methodology is similar to Leathan and Winiecke [4]. The records were initially pulled from a Google Scholar citation report. Then searches using bibliothèque search engines followed. For this analysis, all citations of the Theoretical Model [1],[2] were sought, within the parameters of written in the English language, completed empirical research, and peer reviewed. To manage the records, Clark and Lovric articles, 2008 and 2009, citations were searched separately. Both sets of records, 2008 and 2009 publications, were merged with the removal of any duplicates. Finally, to ensure a thorough search of records, Compendex ERIC, ERC, Ed Full Text, and Psychological and Behavioral Science, Science Reference Source, and Social Science full text were searched with a date range from 2008 to the present, 2024.

The records search for citations of the Theoretical Model for Secondary Tertiary Transition in Mathematics [1],[2] was conducted in November 2024. Two Google Scholar citation reports were extracted, one for the 2008 article [1] and one for the 2009 article [2]. For the 2008 article, the Google Scholar citation report yielded 167 records. Following review, 78 records were removed because they were duplicates, not in English language, gray literature, not peer reviewed, no Clark and Lovric 2008 reference, or not a record (i.e. blog). A citation search was completed on Web of Science, with peer reviewed articles written in English language which yielded 47 articles where 2 new records were found. The same process was completed using Scopus, where 2 new records were found. This process was repeated for the 2009 article. Once both sets of records, 2008 and 2009, were combined and duplicates removed, there were 148 records. To ensure, all records available were discovered, bibliographic databases were searched. A Compendex search was completed, which includes Engineering Village. The following terms were searched “secondary tertiary transition* AND math* ed*” with the parameters of since 2008, available in English language, and peer reviewed. Twenty-one records were produced. One was not in English language, two were already discovered, and eighteen did not reference Clark and Lovric [1],[2]. Therefore, no new articles were found from this search. Using ERIC, ERC, Education Full Text, Psychology and Behavioral Science, Science Reference Source, and Social Science full text another search was completed with the same parameters as the Compendex search. First search terms were “secondary tertiary transition* AND engineer*”, and the second search terms were “secondary tertiary transition* AND math* ed*”. Neither search provided new records. The 148 found articles were reviewed. Initially, 75 records met the predetermined criteria of written in the English language, completed empirical research, peer reviewed and citing Clark and Lovric’s 2008 and/or 2009 articles. Upon reviewing the citations, it was noted that the context of 3 records and citations were the mathematics transition from primary school to secondary school. These articles were excluded because they are outside the focus of this analysis. Therefore, 72 article and proceeding publications were coded. See Appendix A.

Each record was uploaded into MAXQDA for analysis. Initially, descriptive data was extracted, see Table I. Then each citation was coded a priori from identified themes from the Theoretical Model for Secondary-Tertiary Transition in Mathematics (Table II). Qualitative deductive analysis [8] of the citations of Clark and Lovric 2008 [1] and 2009 [2] articles was completed. Ultimately, there are 165 citations with 243 codes in the first coding. Some citations have more than one code; for example, “In tertiary mathematics courses students are exposed to the introduction of abstract concepts and formal reasoning; they witness an increased emphasis on the precision and rigor of the mathematical language, and this is very new for them (shock of the new) (Clark & Lovric, 2009)” [9]. This was coded as cognitive conflict and shock/crisis. One 2008 article citation was coded as not aligned with the model because the citation claimed that Theoretical Model solely considered academics. Although academics was a focus in the model, it also considered the student’s communities and the student’s affective responses [1] in the transition.

TABLE I
DESCRIPTIVE DATA

Descriptor	**Fields**
Publication	Publication Name Year Published Type of Record: Article or Proceeding

Citations	Clark and Lovric Article(s) Cited Number of Citations per record
Research Article	Participants Context Section of Research Is Rite of Passage the Theoretical Framework?

TABLE II
THEORETICAL MODEL THEMES FROM THEORETICAL MODEL FOR SECONDARY TERTIARY TRANSITION IN MATHEMATICS [1,2]

Theme	**Description**	**Example**
Rite of Passage	A definition, characterization, or description of the anthropological origin of secondary tertiary mathematical transition with or without phases.	"However, Clark and Lovric (2009) postulate that the transition from high school to university, also, can be conceptualized as a rite of passage, and, therefore aligned with the three phases of separation, transition, and incorporation" [10, p. 194]
Affective	The attitudes, beliefs, motivation, and emotions of students.	"…and emotional responses to institutional changes (Clark & Lovric, 2008)" [11, p. 60]
Student Autonomy	The student independently meeting expectations, responsibilities, and demands of the secondary to tertiary mathematical transition.	"For this reason, they are more frequent as the students' progress through different educational stages, where they are urged to be more flexible and autonomous (Clark & Lovric, 2008)" [12, p. 301]
Student's Community	People who have an interest in the outcome of the transition, familiar with the process, and are aware of their responsibility to the students. Students should also help each other.	"As part of our inquiry into students experience in STT, we sought to capture which mechanisms they identified as providing social or academic forms of support (Clark & Lovric, 2009)" [13, p. 170]
Shock/Crisis	An emotional reaction to a new situation characterized by confusion, anxiety, and uncertainty.	"The findings of their research seem to concur with the culture shock described by Clark and Lovric during the transition to higher education and the result on the negative effect on students upon arrival in a third level mathematics classroom" [14, p. 3170]
Cognitive Conflict	New knowledge in college mathematics is incompatible with old knowledge. Students are transitioning from surface level learning and informal language to formal language and a deep understanding. Tertiary is also primarily conceptual knowledge whereas secondary is primarily procedural.	"However, as students make the leap to university, the dynamics of mathematical writing undergo a paradigm shift, demanding the construction of formal definitions and the adept use of formal language and reasoning (Clark & Lovric, 2009)" [15, p. 37]
Discontinuity	Lack of continuity from secondary to tertiary instruction. There is a lack of communication between secondary and	"Furthermore, when students enter university, they are unaware of numerous aspects of university life and the ways in

	tertiary instructions. Each also have different strategies for mathematical reasoning and proof.	which academic requirements will change from those they were used to at school (Clark and Lovric 2008).” [16, p. 167]
Synthetic Model	Student’s misconceptions due to a mixture of belief and math fact, which must be unlearned.	“If they grasp concepts but cannot connect them to relevant procedures, flawed procedures develop into what Clark and Lovric (2009) referred to as a synthetic model.” [17, p. 7]
Remedial Efforts	Due to the divergence of secondary and tertiary mathematics goals, students may need to be retaught mathematics. This category also includes interventions.	“However, simply reteaching prerequisites with the same method used in high school, did not seem effective (Clark & Lovric, 2008).” [18, p. 2]
Time	After a graduation from high school and before college begins, a gap in mathematical education may occur, which leans to learning loss. The rite of passage takes time. Building a new community in college takes time. Students need time for individual mathematics practice. Mathematics in the final years of high school are critical.	“Clark and Lovric (2009) proposed a transition model based on the anthropological concept of a rite of passage, arguing that the transition takes time…” [19, p. 763]

Each of the 72 articles were coded twice to check for consistency in coding. Initial coding was in December 2024 and second coding was March 2025. In December there were 243 codes, and in March there are 247 codes. Using MAXQDA software, the comparison between each set of codes was completed based on the code occurrence in the articles and the code frequency in the articles. The percentage of the 72 documents with 100% agreement based on code occurrence is 84.72% and based on code frequency is 81.94%. The agreement of codes based on code occurrence is 98.15% where discontinuity, autonomy, and not aligned were in 100% agreement. And the agreement of the codes based on the code frequency was 97.22% with autonomy, discontinuity, and not aligned in 100% agreement. The code occurrence agreement for the articles is 98.15%, and code frequency for the articles is 97.22%. After two weeks, discrepancies in coding were resolved. The final for this analysis is 250 codes across 72 articles.

Findings and discussion

The publications are sourced from a wide range of mathematics education journal and proceeding publications. The journal with the most records referencing Clark and Lovric [1],[2] was *International Journal of Mathematics Education in Science and Technology* with 11 articles. This is also the journal that published Clark and Lovric 2009 article. According to the journal’s mission, the journal has an interest in communication between mathematics researchers and practitioners, and the journal seeks mathematic pedagogical research [20].

Overall, the publications citing Clark and Lovric are concerned with the mathematics education of engineering students, even if it is by proxy. There were no records located that were published in engineering education journals or conference proceedings, but citations in research related to mathematics preparation of engineering students was consistently present. Fifteen records specifically listed engineering majors as the participants, and although the context of the articles citing Clark and Lovric was mainly associated with university mathematics departments, engineering students are required to take the courses of note, specifically calculus. Therefore, engineering majors are often included in the research as students in a mathematics course. In addition to university mathematics departments and calculus courses, university engineering departments are the context of six articles.

The publication years of the records range from 2010 to 2024. A breakdown of the number of publications referencing the theoretical model is in Fig. 1. The use of the model has increased over time with the most records published in 2023 based on a November 2024 record retrieval.

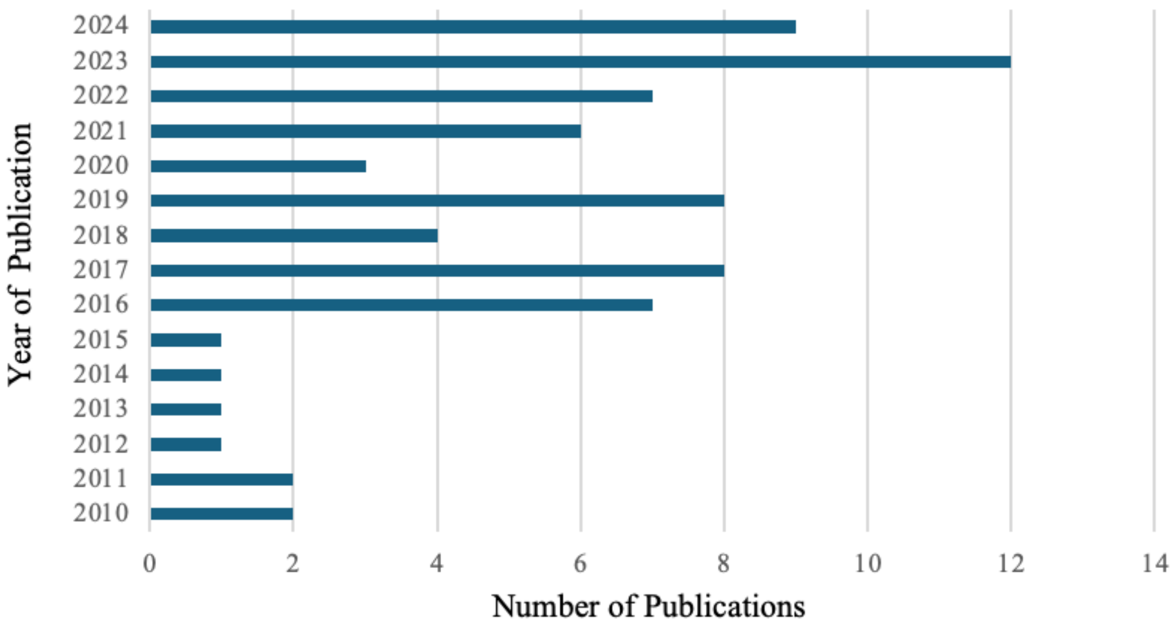

Fig. 1. Year of publication and the number of records citing Clark and Lovric [1],[2]

There are 165 citations across the 72 records. Some authors cited both the 2008 and 2009 articles by Clark and Lovric, but the majority cited only one of the articles, Fig. 2. The number of citations per article ranges from one to nine. For the number of citations per record, a box and whiskers was created, Fig 3. The records with 8 and 9 citations are outliers. With the inclusion of the outliers, the mean is 2.3 citations per record with a mode of 1 and a median of 2.

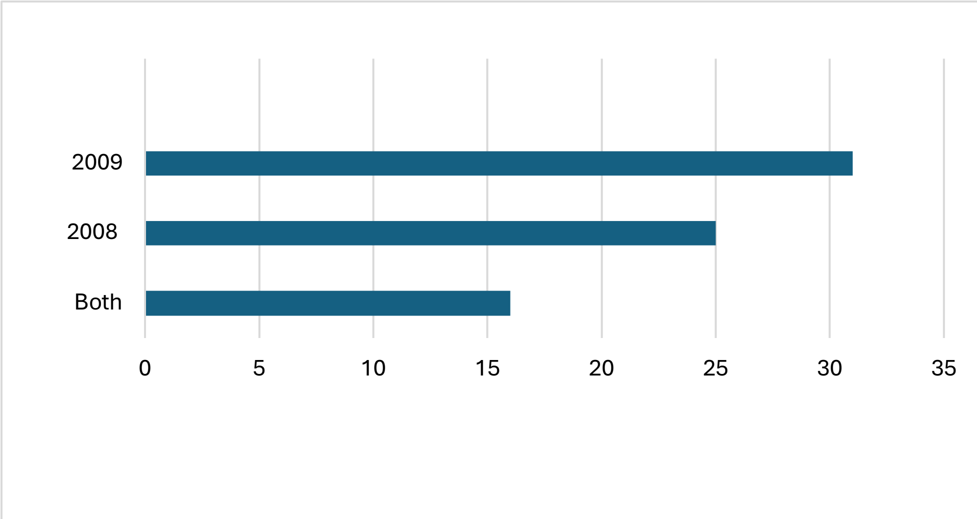

Fig. 2. Clark and Lovric Article(s) [1],[2] and number of citations.

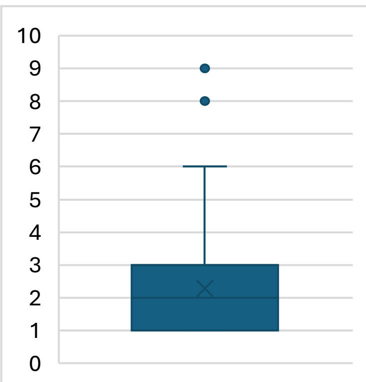

Fig. 3. Distribution of Citations by Record

The section of the empirical research where the citations are found provides insight into the primary purpose of the model. See Fig. 4. The introduction was the most common section to find a rite of passage citation followed by the literature review and discussion sections. By using the Theoretical Model for the Secondary-Tertiary Transition in Mathematics in the introduction, the researchers are establishing the problem or issue the research will address [21], the literature review provides an overview of current publications on the research problem [21], and in the discussion section, the researcher is interpreting their findings [21]. Although Clark and Lovric articles are cited in the theoretical framework section of research, only a few used the Theoretical Model as their theoretical framework.

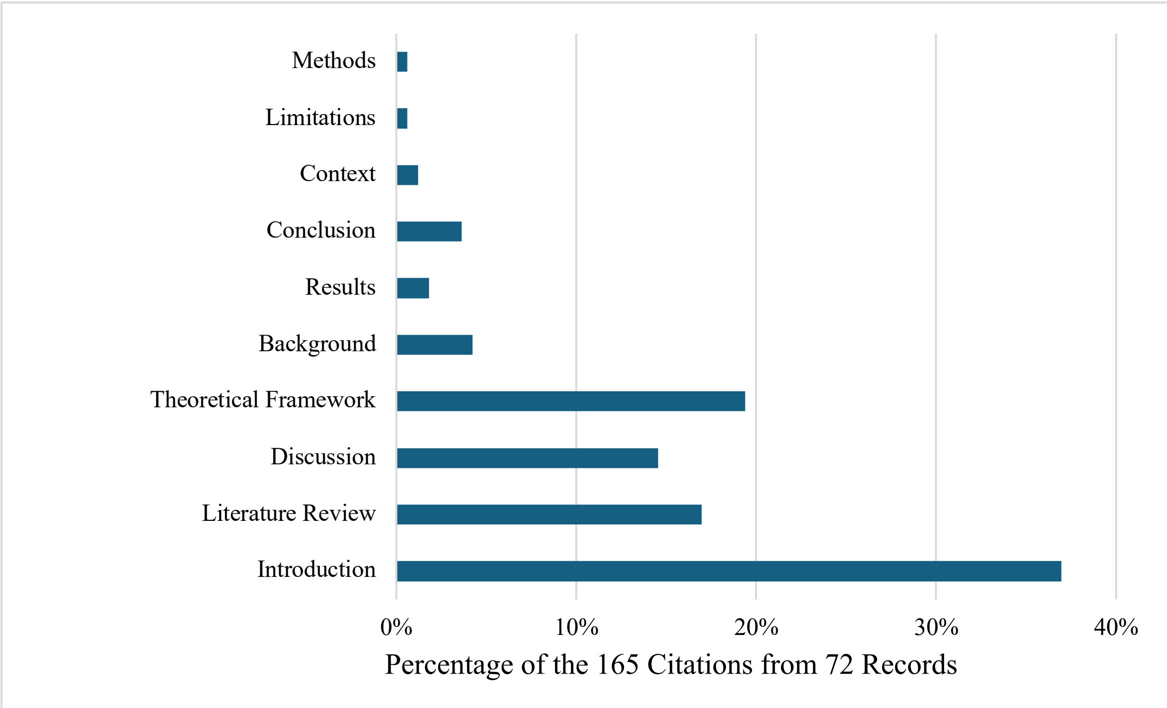

Fig. 4. Location in records where authors cited Clark and Lovric [1],[2]

Using the themes found in Table III, each citation was coded by qualitative deductive analysis [8] in MAXQDA. Most of the codes, 24.4%, were the Rite of Passage theme, which is a characterization or definition of the transition. Cognitive Conflict, 17.6%, Discontinuity, 17.6%, and Shock/Crisis, 9.6%, themes had the next most common instances. The student autonomy, student's community, and affective factors are in the middle range of citation occurrences. Time, remedial efforts, and synthetic model were the smallest percentages. Upon reviewing Table III, it appears that the cognitive and pedagogical differences between secondary and tertiary mathematics courses are cited the most.

Cognitive Conflict, Discontinuity, and Shock/Crisis themes are connected. Shock/Crisis theme describes the transition as painful, unavoidable, and stressful [1],[2]. However, this theme also includes the shock of college mathematics [1], [2], which lends to the cognitive conflict and discontinuity theme. Several citations in the discontinuity theme mention the lack of communication between secondary and tertiary mathematics instructors. For example, "This data confirms that high school students seemed to have an incorrect perception of the gap between secondary and tertiary mathematics. According to Clark and Lovric (2008), this is one of the major causes of failure in the transition and relates to the poor communication between secondary level and university" [22, p. 835]. Only one citation references inflated grades in secondary mathematics. "One factor that appears to have a significant effect on the predictive value of high school grades on university is grade inflation" [23, p. 1234]. For the affective theme, the student's attitude toward mathematics is reflected in the citations as well as their emotions related to the disruption in their routine.

Remedial efforts, 4.8%, and synthetic model, 1.6%, themes describe how students struggle once they are in college mathematics. The citations coded as remedial efforts were focused on ways college remedial efforts could be ineffective and decrease student's motivation. There were not many citations about the synthetic model, which is where the student assimilates prior mathematics knowledge into new knowledge possibly leading to flawed mathematics procedures [1], [18].

The citations of the themes Student Autonomy, 7.6%, and Student's Community, 7.6% reflect the students need to be independent and build their social and academic communities in the university setting [1], [2]. Student Autonomy and Time, 2.8%, themes were coded together when the records reported the student needs to be independent and make the time to study [9]. Although the theme of time was not cited often, it is present throughout the theoretical model. When it is cited, the influence of time primarily relates to (a) the students' ability to manage their time when they are in college, (b) the time it takes to emotionally and physically make the secondary-tertiary transition, and (c) time to develop mathematics skills.

TABLE III
NUMBER OF CITATIONS ASSOCIATED WITH THEMES

Theme	**Citations Codes**	**Percentage**
Rite of Passage	61	24.4
Affective	15	6.0
Student Autonomy	19	7.6
Student's Community	19	7.6
Shock/Crisis	24	9.6
Cognitive Conflict	44	17.6
Discontinuity	44	17.6
Synthetic Model	4	1.6
Remedial Efforts	12	4.8
Time	7	2.8
Not Aligned with Model	1	0.4
Total	250	100

Conclusion

This citation analysis sought to understand the influence that the Theoretical Model for Secondary-Tertiary Transition in Mathematics had on research and how the field has utilized the model. The primary influence on research is the acceptance that the transition from secondary to tertiary mathematics aligns with the Rite of Passage, which is necessary and often arduous [1],[2]. The citations also focus on the differences in secondary and tertiary mathematics. Secondary and tertiary mathematics may have the same course title but generally feel disjointed and dissimilar with a lack of communication between the secondary and tertiary educators. The citations acknowledge college students need to be independent and build a college community for support [1],[2].

Student Autonomy and Student's Community themes were cited by researchers predominantly referencing universities. Although the focus was more towards building a community in college, the guidance counselor, secondary teachers, family, church, friends, and peers are listed as part of the student's community in the Theoretical Model [2]. In this analysis, beyond the secondary mathematics instructor, no citation referenced the student's community in high school. According to Clark and Lovric community members are "involved in a rite of passage are familiar with the whole process, interested in its outcome, and fully aware of their roles and responsibilities" [2, p. 761]. Although this is the ideal, it "does not characterize the community related to the transition from secondary to tertiary education" [2, p. 761]. Admittedly, this citation analysis is a narrow portion of secondary tertiary mathematics transition research, and there may be research that considers the student's high school community when preparing for the college requirements of mathematics heavy majors, even if it is not ideal. But, in this analysis, the high school's role in the secondary tertiary mathematics transition was not evident.

The preparation to major in engineering begins prior to college. The Theoretical Model for Secondary-Tertiary Transition in Mathematics states that the better the student is informed about the transition from secondary to tertiary mathematics the smoother the transition [1,2]. Are most secondary students receiving accurate information about tertiary mathematics requirements? According to the model the student's community is familiar with the process of transitioning from secondary to tertiary mathematics, but if the student's high school community is unfamiliar with the expectations, the information could be made available to them.

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Appendix A
List of Records

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