# Potential High School Teacher Candidates' Mathematical Content Knowledge as Evidenced in their Advanced Mathematics Portfolios

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**Abstract**

The purpose of this study was to measure potential high school teacher candidates' mathematical content knowledge as evidenced in their advanced mathematics portfolios. The study also measured candidates' ability to demonstrate how their learning of mathematics at the university level applies to the teaching of high school mathematics. Based on the quantitative and qualitative analysis of candidate portfolios, it was determined that the majority of high school teacher candidates have difficulty demonstrating their mathematical ability fully, especially their ability to make connections between mathematical content areas, and between content and process standards. It is suggested that the portfolio assessment should emphasize the use of fewer problems that have rich connections, rather than more problems that have little or no connections.



## Background and Research Questions

In the last decade, portfolio assessment has received increased attention in the field of teacher education. A variety of books and papers have been published encouraging the use of portfolios to measure teacher candidates' performance (e.g., Costantino, DeLorenzo, & Kobrinski, 2006; Deveci, Ersoy, & Ersoy, 2006). A portfolio is a collection of work that demonstrates students' progress and achievement with respect to certain standards and goals (Mullin, 1998). Unlike most other forms of assessment, portfolios allow students to be actively engaged in selecting and reflecting on their work, which provides an opportunity for students to demonstrate their growth of knowledge (Lambdin & Walker, 1994). Although maintaining validity and reliability of portfolio assessment has been found to be challenging (Koretz, 1998), proponents of portfolio assessment have praised it for its ability to measure student performance and improve instruction (Klenowski, 2000).

This paper illustrates how two faculty members (in mathematics and mathematics education) collaborated to develop a mathematics portfolio assessment in a capstone course entitled *Advanced Mathematics for High School Teaching*. In this course, teacher candidates were required to complete a portfolio based on specific competencies as outlined in the National Council for the Accreditation of Teacher Education and the National Council of Teachers of Mathematics (NCATE/NCTM, 2003) standards. In their portfolios, students were required to demonstrate their knowledge of central mathematics concepts in calculus, discrete mathematics, geometry, and linear and abstract algebra. They were also expected to demonstrate mathematical processes such as problem solving, reasoning and proof, communication, and the connectedness of mathematical knowledge. Finally, they were expected to demonstrate how their learning of mathematics at the university level applies to the teaching of high school mathematics.

This paper seeks to answer the following questions:

- How well do potential high school teacher candidates' portfolios demonstrate their mathematical content knowledge?
- What kinds of mathematical problems do high school teacher candidates select in their advanced mathematics portfolios?



## Methodology

### The Course and Mathematics Portfolio

The setting for the present study was a course developed by the authors entitled *Advanced Mathematics for High School Teaching*. This course is intended to be a capstone course for students (hereafter termed "candidates") seeking secondary mathematics teaching certification in grades 7-12. It attempts to expand and integrate candidates' knowledge of mathematics and investigate the connections between advanced mathematical content and secondary mathematics. The textbook for the course is Usiskin, Peressini, Marchisotto, and Stanley (2003), which requires students to investigate secondary mathematics content in an advanced manner. Course prerequisites include Calculus I and II, Discrete Structures, Geometry, and Linear or Abstract Algebra. It is intended that candidates take the course at the end of their junior year of study, before they apply for admission to teacher certification in secondary mathematics.

The primary data source for this study is candidates' portfolios, which was the major assignment in the *Advanced Mathematics for High School Teaching* course. The portfolio assignment focused on 13 of the 16 NCATE/NCTM (2003) standards. Six of these 13 standards comprise the Process standards, as they concern the process of learning mathematics: Mathematical problem solving, reasoning and proof, mathematical communication, mathematical connections, mathematical representation, and technology. The other seven standards, the Content standards, involve the content of undergraduate mathematics: Number and operation, algebra, geometry, calculus, discrete mathematics, data analysis, statistics, and probability, and measurement. (The other three standards, mathematical dispositions, mathematical pedagogy, and field-based experiences, do not emphasize mathematical content knowledge or mathematical processes and were omitted from this particular assessment system.) To create their portfolios, candidates utilized such items as problem sets, activities, puzzles, projects, technological applications, and proofs, drawn from classes or their independent library research, that demonstrated specific competencies as outlined in the NCATE/NCTM standards. Candidates were also required to write commentaries and reflections throughout their portfolios and clearly state how their portfolio entries relate to the teaching of high school mathematics topics.

After having completed the portfolio assignment, four candidates were selected for and volunteered to be interviewed. These four candidates represented four different ability levels as demonstrated in the portfolios. The primary purpose of interviews was to investigate factors that influenced candidates' thinking about problem selection and reflection. Another purpose was to find out if the candidates had any suggestions to improve the portfolio assessment system. All of the interviews were audiotaped and transcribed.

**Portfolio Assessment: A Collaborative Approach**



Both authors collaborated in developing the portfolio guidelines and a rubric (see the Appendix) to measure the candidates' mathematical proficiencies. The rubric includes quantitative and qualitative descriptors of candidates' abilities to demonstrate their understanding of the NCATE/NCTM standards. It focuses on mathematical correctness, elegance, and the ability to connect advanced university mathematics to high school topics. For each standard, candidates were required to select two problems that demonstrated their understanding of that standard. For example, in the standard Mathematical problem solving, candidates were required to provide two examples that demonstrated their ability to solve mathematical problems and to explain why they selected those problems. In addition, they had to justify how the problems would help them in the teaching of mathematics at the secondary level.

Candidates were given a score of 3 (target performance) for a content or process standard if they demonstrated an in-depth knowledge of mathematics content and processes by addressing all of the indicators included in the standard and by reflecting on how they could use the selected work to teach high school mathematics. They would get a score of 2 (acceptable score) if they demonstrated solid knowledge of mathematics by addressing 80% of the indicators and by providing some connections of the selected work to the teaching of high school mathematics. (In order to meet the guidelines for NCATE accreditation, a program is required to demonstrate their candidates meet 80% of the indicators in each standard.) They would get a score of 1 (unacceptable) if they failed to address 80% of the indicators or failed to show connections between the selected work and high school mathematics. They would get a score of 0 if there was no response or the response provided did not make sense to the raters. The full rubric is provided in the Appendix.

## Data Analysis Procedure

Both quantitative and qualitative methods were used in this study. There were 17 candidates who completed the portfolio assessment in the *Advanced Mathematics for High School Teaching* course. These portfolios were independently scored by the authors. Means of the two ratings were computed for each candidate for each standard, for all process standards and all content standards, and for the full group of 13 standards. Spearman rank correlation coefficients were also calculated to investigate the interrater consistency between the two raters.

After rating the entire set of portfolios, the two raters met to determine possible sources of inconsistencies in the ratings. During these meetings, a substantial amount of time was spent to reflect on the validity of the mathematics portfolio as an assessment system. The authors determined that taken together, the portfolios did not reflect the vision they had at the start of this project. As a result of these meetings, the authors determined that the ratings themselves were not sufficient to fully understand the issues raised by the portfolio assessment system.

Accordingly, a qualitative analysis was conducted on the set of portfolios. To carry this out, the constant comparative method (Glaser & Strauss, 1967) was used. Each of the 17 portfolios was analyzed to generate themes. A theme in a portfolio was determined only if there were at least three instances of the same pattern in that portfolio. When a theme was noticed in one portfolio it was carefully compared to all of the remaining 17 portfolios. For the purpose of this article, a theme was identified only if it appeared in at least three portfolios.



## Results

At the individual level, mean scores for the entire portfolio ranged from 0.58 to 2.92; however, there were only 3 candidates whose mean score was below 1.50. The overall mean score of all items for all candidates was 1.84. The overall mean for all process standards was 2.01 (acceptable), and for all content standards 1.71 (unacceptable). The difference between process and content standards was statistically significant ($t = 2.839$, $df = 168$, $p = 0.005$).

Candidates' scores were highest in the technology standard (2.24) and lowest in the number and operation standard (1.62). The majority of the candidates successfully demonstrated their ability to integrate technology into mathematical content and process standards by using computer applications such as Geometer's Sketchpad, Maple, and Minitab. Others effectively used the graphing calculator to demonstrate that they were competent in using technology for the learning and teaching of mathematics.

The raters were initially surprised that the lowest average score was in the number and operation standard. Based on the qualitative analysis and the interviews with four of the candidates, there appear to be two primary reasons for the low scores on this standard. Many candidates included problems that were too elementary, making the assumption that for the number and operation standard they could use easy problems, which may not necessarily represent advanced university level mathematics. The candidates were also challenged by the large number of indicators (10) that they had to address in this particular standard.

Interrater consistency analysis revealed that there was higher percent agreement on the process standards (55.3%) than on the content standards

(39.5%); overall agreement was 46.1%. Spearman rank correlation coefficients between the two raters indicated a reasonable degree of consistency: for the process standards, r = 0.724 (p = 0.001); for the content standards, r = 0.625 (p = 0.007); and for all standards, r = 0.739 (p < 0.001). These measures of consistency are similar to those reported by previous researchers (e.g., Baume & Yorke, 2002).

The authors agreed that three out of 17 candidates best demonstrated the intent of the portfolio assignment. These three candidates were able to demonstrate their mathematical content knowledge by consistently showing inherent connections among mathematical content areas, and between content and process standards. They included non-routine and open-ended problems that demonstrated how advanced university mathematics is deeply connected to the teaching of high school mathematics. For example, one of these candidates included a problem to find the formula for the volume of a sphere using calculus, and included it in the mathematical connections, mathematical representation, geometry, and calculus standards. Another candidate included a problem to find an equation describing the carbon dioxide level in the atmosphere as a function of time, and included it in both the calculus and probability and statistics standards.

Such deeply connected problems, however, were not included in the majority of candidates' portfolios. The qualitative data analysis of candidates' portfolios showed the majority exhibited one or more of the following themes: 1) Too few connections between mathematical content areas, and between content and process standards; 2) Problems selected too elementary; and 3) Limited connection of college level mathematics to the teaching of high school mathematics.

### Too Few Connections between Mathematical Content Areas, and between Content and Process Standards

Many of the portfolios had few or no connections between the problems included within. Overall, there were 318 problems included in the 17 portfolios, an average of 18.7 problems per portfolio, with a range from 7 to 36. Of the 318 problems, 76 were used by a candidate in discussing more than one standard, an average of just over 4 such problems per portfolio. Six of the portfolios had no such problems or only a single such problem. The lack of connections is particularly striking when considering only the content standards. There were 24 problems that were used to discuss more than one content standard; 7 of the 17 portfolios had no examples of problems used for more than one content standard, and an additional two portfolios had a single problem that was used for more than one content standard. This shows that the majority of candidates did not meaningfully demonstrate the connectedness of their mathematical content knowledge. Many such candidates included a large number of problems that could be solved by simple mathematical manipulations, such as finding the derivative of a given function using the chain rule or a straightforward proof of the Pythagorean Theorem. These were routine problems or exercises simply taken from a mathematics text or coursework. As noted previously, there would be more opportunity to show connections if the problems selected were non-routine and open-ended.

There were a number of candidates who had included problems in their portfolios that could have been easily used for more than one content or process standard, but were not. For example, one candidate used an optimization problem for problem solving, which could have been easily used to address number and operation and algebra standards. Another candidate included a physics problem on work and force to demonstrate her ability to apply calculus in physics. Although she included this problem only for calculus, she could have used it to address algebra and problem solving standards. A third candidate used a problem to find the surface area of a sphere of radius *a* to address the calculus standard. This problem could have been used for the geometry and problem solving standards. The connections the authors hoped to see were frequently not made. In the interviews, all four students remarked that they were somewhat overwhelmed by the number of indicators included in the standards, and that they tended to focus on specific indicators rather than the overall standard itself. Because most students focused on each indicator one at a time, they were unable to make meaningful connections between the various content standards. They made more, but still relatively few, connections between the process and content standards.



**Problems Selected too Elementary**

Because this course was an advanced level mathematics course, the candidates were required to include college level problems. For the purposes of data analysis, a fairly liberal definition of "college level" mathematics was used: a problem was considered to be college level mathematics if it involved any content at the level of calculus or above. Proofs were considered to be "college-level" mathematics even if students may typically see a similar proof in a high school geometry course, as long as they included some discussion of non-Euclidean geometry. Similarly, simple probability problems were not considered "college level" mathematics, but more advanced ideas in probability, such as binomial probability, were coded as "college level" mathematics.

The analysis indicated that 97 of the 318 problems (30.5%) in the portfolios were considered not to be "college level" mathematics. This number ranged from a low of 0 (two portfolios, out of 7 and 10 problems respectively) to a high of 16 (out of 23). Following are five examples of problems from five different candidates that were considered too elementary by both raters.

1. Evaluate the expression $(-3^2 + 5 * 6 \div 2) - 2^2 \div 4$ (Number and Operation).
2. A store gives a 30% discount and then an additional 10% discount; find the total discount on a $100 purchase (Algebra)
3. Given A = {1, 3, 5, 7, 10} and B = {2, 4, 6, 8, 10}, find $A \cap B$ (Discrete Mathematics)

4. Find the mean, median, and standard deviation of the set of data 1.1, 0.7, 3.3, 3.1, 5.5, 7.2, 4.2, and 6.3 (Probability and Data Analysis).
5. Represent f(x) = 3x + 4 as a graph and in a table (Mathematical Representation)

In the interviews, all four students indicated that they included problems such as these because a number of specific indicators in the NCATE/NCTM standards include mathematics that is not "college level." However, the portfolio assignment allows a candidate to address these indicators in the context of solving a problem that does involve "college level" mathematics. Again, because candidates tended to focus on the indicators one at a time, they missed the opportunity to do this.

### Limited Connection of College Level Mathematics to the Teaching of High School Mathematics

Three of the 17 candidates demonstrated a deep connection between college-level and high school mathematics. They had a robust view of secondary mathematics and saw multiple connections between secondary and college level mathematics. They stressed that a teacher needs to know not just what appears on a textbook, but why something was true in mathematics. They were willing to try new forms of technology and think about why a student might have difficulty in solving a problem. One of these candidates included the derivation of a formula for the volume of a sphere using calculus and stated that "this problem shows where the formula for spherical volume comes from, rather than just stating it in the appendix of a high school geometry book." Another candidate included a problem on projectile motion and stated that this was an example of a problem in which two faculty members (mathematics and physics) can work together. The problem clearly required a solid understanding of high school mathematics and understanding the problem provided a solid background on teaching concepts like slope and rate of change.

The remaining 14 candidates demonstrated a limited connection between college and high school mathematics. Their ideas were either too general or were limited to whether a problem can be used with a high school class, or whether a problem will be "easy" for students. Overall, there were some candidates who made comments about the importance of understanding the mathematics they would be teaching at the high school level, but the majority of comments candidates made were on whether a given problem could be "used with" or "given to" a high school student, without consideration of the connections between secondary and more advanced mathematical content.

For example, a candidate included the Pythagorean Theorem in her portfolio and stated that "this proof would be perfect for the secondary level, [because] showing this proof to the students and explaining each step in depth to each student would be very helpful to them in the end." There was no explanation of why a step by step description of a proof was going to be useful for students. Another candidate included a problem to find the area under the function f(x) = 2x + 1 from 0 to 1, completed in a calculus class, and stated that this problem allows the teacher to check if "they know that they should integrate from 0 to 1 of (2x + 1)" [*sic*]. While the problem was correctly solved, it failed to show the connection between calculus and high school algebra and geometry. This problem could also have been solved by using the graph of f(x) = 2x + 1 and finding the area under the straight line from 0 to 1 without using calculus. This would help not only to show connections between high school and college mathematics but also to appreciate the power of calculus in solving problems that are not amenable to such methods.



## Conclusions and Implications

Consistent with previous researchers (e.g., Klenowski, 2000), the authors found that portfolio assessment can be used both to measure student performance and improve instruction. This study has provided insights into teacher candidates' problem section and reflection, mathematical content knowledge, and ability to connect college level mathematics to the teaching of high school mathematics. While some candidates were able to demonstrate their mathematical ability in their portfolios satisfactorily, the majority of candidates did not demonstrate their mathematical ability fully. They made too few connections between mathematical content areas, and between content and process standards. They focused on each indicator one at a time and selected too many small problems that were not generalizable to other mathematical areas. Also, the problems candidates selected were frequently too elementary, and connections to secondary mathematics focused mostly on "giving" certain problems to students when teaching high school.

The process of creating a suitable portfolio assignment and scoring rubric for the *Advanced Mathematics for High School Teaching* course was not as simple as it had been envisioned. For example, despite repeated emphasis throughout the course on using the portfolios to exhibit mathematical understanding and the connectedness of mathematics, some candidates were confused about what kinds of entries and reflections were acceptable in this portfolio. Making connections between mathematical content areas, and between processes and content, did not occur simply by asking candidates to do so.

An obvious goal for a mathematics major pursuing secondary certification is that he or she has a deep understanding of mathematics and is able to make connections between that mathematical knowledge and the topics he or she will teach. The *Advanced Mathematics for High School Teaching* course is the ideal setting to investigate the degree to which this actually occurs. Based on the results of this study, the course, portfolio guidelines, and rubric are being revised. It is expected that the revised portfolio guidelines and rubric will help candidates understand course expectations and create better mathematics portfolios in the future.

Simon and Forgette-Giroux (2000) indicated that a portfolio should be guided by effective "content selection framework." In the current study this translates to problem selection and reflection. As described earlier, a significant proportion of teacher candidates included problems that were either too elementary or that failed to show connections between content areas and between content and process standards. A new study focusing on content selection process, particularly the effects of using fewer problems that have rich connections, would contribute to portfolio assessment process in teacher education.

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## Appendix
## Scoring Rubric for Portfolio Assignment

| Mathematical Problem Solving |
|---|
| **Target (3):** Provides at least two examples and reflection that demonstrate candidate's understanding of the mathematical problem solving standard in all of the indicators suggested by the NCTM/NCATE.<br>Also explains various strategies of solving selected problems, and how they can be used to teach secondary school mathematics. |
| **Acceptable (2):** Provides at least one example and reflection that demonstrate candidate's understanding of the mathematical problem solving standard in at least 80% of the indicators suggested by the NCTM/NCATE.<br>Also explains some strategies of solving selected problems, and how they can be used to teach secondary school mathematics. |
| **Unacceptable (0-1):** No meaningful example related to problem solving is provided. Lacks reflection |

| Mathematical Reasoning and Proof |
|---|
| **Target (3):** Contains at least two examples that can be used to demonstrate candidate understanding of mathematical reasoning and proof standard in all of the indicators suggested by the NCTM/NCATE.<br>The candidate writes appropriate reasoning/proof and explains how these reasoning/proof can be used with high school students depending on their mathematical maturity. |
| **Acceptable (2):** Contains at least one example that can be used to demonstrate candidate understanding of mathematical reasoning and proof standard in at least 80% of the indicators suggested by the NCTM/NCATE.<br>The candidate writes reasoning/proof and explains how these reasoning/proof can be used with high school students. |
| **Unacceptable (0-1):** No example is provided or lacks the demonstration of reasoning and proof. |

| Mathematical Communication |
|---|
| **Target (3):** The candidate uses the language of mathematics to organize his/her mathematical ideas and communicate his/her mathematical thinking clearly, coherently and precisely. The candidate also uses the language of mathematics to analyze and evaluate mathematical thinking and strategies used by others |
| **Acceptable (2):** The candidate uses the language of mathematics to organize his/her mathematical ideas and communicate his/her mathematical thinking clearly and coherently. The candidate also uses the language of mathematics to analyze and evaluate mathematical strategies used by others |
| **Unacceptable (0-1):** No use of the language of mathematics and their precise use. |

| Mathematical Connections |
|---|
| **Target (3):** Contains at least two examples and reflection to demonstrate how mathematics is connected within its own discipline and also in contexts outside of mathematics. |
| **Acceptable (2):** Contains at least one example and reflection to demonstrate how mathematics is connected within its own discipline and also in contexts outside of mathematics. |
| **Unacceptable (0-1):** No example and reflection to demonstrate how mathematics is connected within its own discipline and also in contexts outside of mathematics. |

| Mathematical Representation |
| --- |
| **Target (3):** Provides at least two examples and reflection that explain how representations are created and used to organize, record, and communicate mathematical ideas and to model and solve mathematical problems. |
| **Acceptable (2):** Provides at least one example and reflection that show how representations are created and used to organize, record, and communicate mathematical ideas and to model and solve mathematical problems. |
| **Unacceptable (0-1):** No meaningful example and reflection are provided. |



| Technology |
| --- |
| **Target (3):** Uses knowledge of mathematics to select and use appropriate technological tools, such as but not limited to, spreadsheets, dynamic graphing tools, computer algebra systems, dynamic statistical packages, graphing calculators, data-collection devices, and presentation software. |
| **Acceptable (2):** Uses knowledge of mathematics to select and use at least 80% of the following technological tools: Spreadsheets, dynamic graphing tools, computer algebra systems, dynamic statistical packages, graphing calculators, data-collection devices, and presentation software. |
| **Unacceptable (0-1):** No evidence of appropriate technological tools. |
| **Number and Operation** |
| **Target (3):** Provides at least two examples and reflection that demonstrate candidate's understanding of the number and operation standard in all of the indicators suggested by the NCTM/NCATE.<br>Also explains how they can be used to teach secondary school mathematics. |
| **Acceptable (2):** Provides at least one example and reflection that demonstrate candidate's understanding of the number and operation standard in at least 80% of the indicators suggested by the NCTM/NCATE.<br>Also explains how they can be used to teach secondary school mathematics. |
| **Unacceptable (0-1):** No meaningful example and reflection are provided. |

| Algebra |
| --- |
| **Target (3):** Provides at least two examples and reflection that demonstrate candidate's understanding of the algebra standard in all of the indicators suggested by the NCTM/NCATE.<br>Also explains how they can be used to teach secondary school mathematics. |
| **Acceptable (2):** Provides at least one example and reflection that demonstrate candidate's understanding of the algebra standard in at least 80% of the indicators suggested by the NCTM/NCATE.<br>Also explains how they can be used to teach secondary school mathematics. |
| **Unacceptable (0-1):** No meaningful example and reflection are provided. |

| Geometry |
| --- |
| **Target (3):** Provides at least two examples and reflection that demonstrate candidate's understanding of the geometry standard in all of the indicators suggested by the NCTM/NCATE.<br>Also explains how they can be used to teach secondary school mathematics. |
| **Acceptable (2):** Provides at least one example and reflection that demonstrate candidate's understanding of the geometry standard in at least 80% of the indicators suggested by the NCTM/NCATE.<br>Also explains how they can be used to teach secondary school mathematics. |
| **Unacceptable (0-1):** No meaningful example and reflection are provided. |

| Calculus |
| --- |
| **Target (3):** Provides at least two examples and reflection that demonstrate candidate's understanding of the calculus standard in all of the indicators suggested by the NCTM/NCATE. Also explains how they can be used to teach secondary school mathematics. |
| **Acceptable (2)**: Provides at least one example and reflection that demonstrate candidate's understanding of the calculus standard in at least 80% of the indicators suggested by the NCTM/NCATE. Also explains how they can be used to teach secondary school mathematics. |
| **Unacceptable (0-1):** No meaningful example and reflection are provided. |



| Discrete Mathematics |
| --- |
| **Target (3):** Provides at least two examples and reflection that demonstrate candidate's understanding of the discrete mathematics standard in all of the indicators suggested by the NCTM/NCATE. Also explains how they can be used to teach secondary school mathematics. |
| **Acceptable (2):** Provides at least one example and reflection that demonstrate candidate's understanding of the discrete mathematics standard in at least 80% of the indicators suggested by the NCTM/NCATE. Also explains how they can be used to teach secondary school mathematics. |
| **Unacceptable (0-1):** No meaningful example and reflection are provided. |

| Data Analysis, Statistics, and Probability |
| --- |
| **Target (3):** Provides at least two examples and reflection that demonstrate candidate's understanding of the data analysis, statistics, and probability standard in all of the indicators suggested b y the NCTM/NCATE. Also explains how they can be used to teach secondary school mathematics. |
| **Acceptable (2):** Provides at least one example and reflection that demonstrate candidate's understanding of the data analysis, statistics, and probability standard in at least 80% of the indicators suggested by the NCTM/NCATE. Also explains how they can be used to teach secondary school mathematics. |
| **Unacceptable (0-1):** No meaningful example and reflection are provided. |

| Measurement |
| --- |
| **Target (3):** Provides at least two examples and reflection that demonstrate candidate's understanding of the measurement standard in all of the indicators suggested by the NCTM/NCATE. Also explains how they can be used to teach secondary school mathematics. |
| **Acceptable (2):** Provides at least one example and reflection that demonstrate candidate's understanding of the measurement standard in at least 80% of the indicators suggested by the NCTM/NCATE. Also explains how they can be used to teach secondary school mathematics. |
| **Unacceptable (0-1):** No meaningful example and reflection are provided. |