Mismatch between the progression of the mathematics course and the level of mathematics required to do advanced physics

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Abstract

Whenever students appear to have trouble with mathematics in their physics courses, they either hate physics or fear it. The blame for this plight could be due to the structure of the mathematics and physics curricula or the incompetence of the teachers. This paper focuses on investigating the progression of the mathematics courses and the level of mathematics required of students in the Department of Physics at the Bahir Dar University, Ethiopia. The key objective of the research is to find out how the mathematics courses are integrated into the physics curriculum especially in terms of providing students with fundamental mathematical skills needed in the corresponding physics courses. A content analysis of the physics curriculum was carried out to determine whether an apparent mismatch or relevant integration exist between the progression of the mathematics courses and the level of mathematics required to learn the physics courses. As a preliminary work, we examined the correlation between student performance (final grade) in the mathematics courses and performance in the physics courses. Despite the significant efforts that gone to improve the undergraduate physics curriculum in Ethiopia, the present study showed that the curriculum made students to attend some senior physics courses without the essential mathematical skills. For example, essential topics in mathematics like vector calculus and partial differential equations are not taught until the end of the second year first term. On the other hand classical mechanics course, which extensively make use of these mathematical topics, begins in the second year first term. Recommendations and implications for physics curriculum and instruction are made.

Keywords: Mismatch, physics curriculum, progression of mathematics courses, advanced physics courses.

Resumen

Siempre que los estudiantes tienen problemas con las Matemáticas en sus cursos de Física, acaban por odiarla o por temerle. La culpa de esta situación podría deberse a la estructura curricular de los programas Física y Matemáticas o a la incompetencia de los profesores. Este trabajo se centra en el progreso que alcanzan los cursos de Matemáticas y el nivel de conocimientos en Matemáticas requerido por los estudiantes del Departamento de Física en la Universidad de "Bahir Dar" en Etiopía. El objetivo clave de la investigación se centra en encontrar cómo son integrados los cursos de Matemáticas en el curriculum de Física, especialmente en términos de proveer al estudiante con las habilidades matemáticas fundamentales, necesarias en los cursos de Física correspondientes. Se llevó a cabo un análisis de contenido del currículo de Física para determinar si una aparente desintegración o integración existe entre el progreso en los cursos de Matemáticas y el nivel de Matemáticas requerido para aprender los cursos de Física. Como trabajo preliminar, examinamos la correlación entre el rendimiento de los alumnos (calificación final) en los cursos de matemáticas y el rendimiento en los cursos de Física. A pesar de los esfuerzos significativos que se han hecho para mejorar el curriculum de los estudiantes de Física de pregrado en Etiopía, el presente estudio mostró que había estudiantes que cursaban la materia de Física en sus últimos temas sin tener todavía las habilidades Matemáticas necesarias. Por ejemplo, los tópicos esenciales en la materia de Matemáticas como el Cálculo Vectorial y Ecuaciones Diferenciales Parciales no son enseñados sino hasta el final del segundo año del primer período. Por otro lado, el curso de Mecánica Clásica, el cual hace uso extensivo de estos tópicos matemáticos, empieza en el segundo año del primer período. Recomendaciones e implicaciones al currículum e instrucción de la Física son hechas.

Palabras clave: Error en el curriculum de Física, progreso de los cursos de Matemáticas, cursos avanzados de Física.

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I. INTRODUCTION

Physics is an important subject that has revolutionized how we live our everyday life today. Since its invention in the 16th century it has experienced various transformations. This transformation brought new technologies and knowledge and therefore physics has been taught in schools, colleges and universities all over the world. Many universities have established a separate physics department where research is carried out in addition to teaching various courses. The field of physics is expanding continuously with new discoveries. Teaching physics is on the other hand is becoming a challenge across the world. One of the widely acknowledged problems in teaching physics is the mathematical nature of physics [1, 2]. To overcome this problem a substantial portion of an undergraduate physics curriculum usually comprises many mathematics courses. Although these mathematical tools are taught in the mathematics classes starting from first year, inadequate mathematical skills present a widespread problem throughout physics undergraduate programs [3, 1]. Students must have been taught the mathematics to the extent that they can use it with confidence in their physics courses. However, requiring more course work does not seem like the answer [4].

In a physics program, the horizontal integration of mathematical courses that contain essential skills needed in learning physics are sometimes lacking. This makes it difficult for the students to grasp or follow the course in physics. For example Tuminaro [4] point out that many physics students perform low on mathematical problem solving tasks in physics. According to Tuminaro, the logic behind this low performance might be due to the lack of students' requisite mathematical knowledge to solve mathematical problems in physics and/or they do not know how to apply the mathematical knowledge they have learned in the mathematics classes taught by mathematician to the context of physics in the physics class [5]. The horizontal integration of mathematics courses with physics has been studied by many researchers. For example, Schalk *et al.* [6] found academic success in mathematics and physics in general to be strongly correlated with positive attitude and interest. According to this report the students who have scored good in mathematics performs well in physics courses. The progression of the mathematics course with the physics course has also been studied by Dray *et al*. [7] and they found in that the syllabi between a vector calculus course and the junior level physics course is not optimized. Boniolo *et al*. [8] have also analyzed what they call Dirac's methodological revolution and they have pointed out that to do innovative physics one should first work on required and prerequisite mathematics. In this context, student success heavily depends on the degree to which the required mathematics and physics are horizontally integrated in order to motivate and engage students in meaningful learning specifically at tertiary level physics programs. The present paper focuses on investigating the progression of the mathematics course and the level of mathematics required of students within the physics undergraduate curriculum in the Department of Physics at the Bahir Dar University, Ethiopia. Exploring the progression of the mathematics courses and comparing it what is needed in the physics undergraduate curriculum could have important implications for physics curriculum modification and instruction mainly in Ethiopia.

II. CONTEXT OF THE STUDY

The physics departments throughout Ethiopian universities have different backgrounds. Most of the universities were opened during the last two decades. Some of these universities have been offering a three year Bachelor of Science (BSc) program, others a Bachelor of Education in Physics (BEd) program while the rest of the universities offered both. The difference between the BEd and the BSc program are the following: the BEd program includes both the subject matter courses (major physics and mathematics courses) and professional courses concurrently during the three year degree program, while the BSc program offer only physics as major courses and mathematics as minor courses. To solver the limitations of the previous curricula (both the BEd and BSc programs) and develop an updated and new curriculum based on the new higher education policy (which emphasizes more students population in natural science than social science enrolment and program mix policy at tertiary education), all universities in Ethiopia were requested, by the Ministry of Education, to carry out a need assessment. Based on the findings of the need assessment, it was evident that the previous curricula, where ever it has been applied in the country, had a number of limitations. The findings have clearly indicated that the previous curricula were content deficient and lacked depth and hence, in order to alleviate these shortcomings, new and dynamic approaches to the curricula were required. In light of these findings, it was essential to harmonize and improve the BSc physics curriculum in the country to meet the required demand of the country. It was evident to start a three year Bachelor of Science (BSc) degree program in physics across all universities. At present, there are 22 universities with physics departments offering three years new BSc degree program in the country. This new BSc physics program was implemented in 2008 based on the new 70 percent natural science and 30 percent social science ratio enrolment and program mix policy. It is on these curricula that, the context of this study is focused on to investigate the progression of the mathematics courses and the level of mathematics required to do senior physics courses.

A. Outline of Course Structure in the new BSc Physics Curriculum

The Department of Physics at the Bahir Dar University offers undergraduate and postgraduate programs for physics majors. Undergraduate courses are offered at three levels: first year, second year and third year. Students studying physics at the university come from different regions of the country. To be admitted into the BSc program with a physics major, a candidate should satisfy the general admission requirements set by Ministry of Education. The undergraduate physics curricula have comprehensive list of courses in physics and mathematics. For the purpose of this research, the list of courses students registered in their first year and second year are indicated in Table I.

As shown in Table I, the required mathematical courses are taught in the first and second year options of the physics curriculum. Therefore, describing an outline of the course structure in the third year program is insignificant for this study. To limit the volume of data collected to a manageable level, the content analysis is limited to those courses offered at the second year.

TABLE I. List of first and second year physics and mathematics courses in the undergraduate physics curriculum at the Bahir Dar University.

List of Compulsory Major/Minor Courses	Year of Study	Semester
Mechanics	I	I
Experimental Physics I	I	I
Calculus I	I	I
Wave and Optics	I	I
Electromagnetism	I	II
Experimental Physics II	I	II
Modern Physics	I	II
Calculus II	I	II
Statistical Physics I	II	I
Mathematical Methods of Physics I	II	I
Classical Mechanics I	II	I
Electronics I	II	I
Modern Optics	II	I
Linear Algebra	II	I
Quantum Mechanics I	II	II
Electrodynamics I	II	II
Mathematical Methods of Physics II	II	II
Nuclear Physics I	II	II
Physics Elective I	II	II

III. PROBLEM STATEMENT: PUROSE OF THE STUDY

The subject of investigating students' difficulties to apply their mathematical knowledge to physics problems at school level is highly complex [9]. The situation is not clear whether the main difficulties can be attributed to the lack of relevant prerequisite mathematical knowledge to solve mathematical problems in physics, a technical skill problem of how to apply the mathematical knowledge they have learned in the mathematics classes to the context of physics or to missing general structural insight. However, the problem does not only manifest in the schools, it seems to increase towards the different stages at tertiary level.

The interplay between mathematics and physics program is seldom studied in developing nations. However, there are a number of good reasons to carry out such study in the Ethiopian context. The progression of mathematics courses with physics programs have not been investigated thoroughly in the Ethiopian context at tertiary level. Moreover, specific well documented examples of student difficulties in using mathematics in physics are often lacking, and the exact nature of the difficulty is often uncertain. In addition, there is little communication between physics and mathematics teachers dedicated to or addressing mathematics skills related issues. Physics teachers usually assume that the mathematical skills are taught in the mathematics courses, but they are often not familiar with the specifics of the mathematics curriculum and how it is delivered. Normally they concentrate their lectures on physics and pay little attention on students difficulties in understanding the mathematics involved in it. This scenario makes many physics graduates incapable of addressing the challenges they are expected to handle in practice. This problem is widely acknowledged in Ethiopia including the Ministry of Education (MOE). When one looks at the problem in relation to the unprecedented emphasis given to science, mathematics, and engineering, it becomes severe. The success of the Plan for Accelerated and Sustained Development to End Poverty (PASDEP), a key government policy, demands the application of science and technology for various sectors in the country. The proper integration of different disciplines is crucial in this regards and little attention, if any, has been paid in the Ethiopian context.

Thus, our goal in this paper is to found out to what extent do the progression of the mathematics courses and the level of mathematics required to do physics courses is considered in the new physics program in Ethiopia. This will be investigated primarily by determining the relation between the predictive values of mathematics academic performance grade point average (GPA) of students and their physics results. Followed by a content analysis to determine whether an apparent mismatch or relevant integration exist between the progression of the mathematics courses and the level of mathematics required to do physics courses. This means that a major component of this study would comprise a thorough analysis to determine the degree to which a student's academic performance in mathematics correlate to his/her physics performance.

A. Research Questions

This study seeks to answer the following research questions:

I. To what extent is BEd physics students' mathematics scores correlated with their scores in physics courses? How is the situation in the new BSc Undergraduate Physics Curriculum, which has been adopted by all universities in Ethiopia?

II. Is there an apparent mismatch between the progression of the mathematics courses and the level of mathematics required to do advanced (senior) physics courses in the new BSc Physics Curriculum?

IV. RESEARCH METHODS AND DATA SOURCES

This study was done in two phases. In the first phase a statistical analysis on the academic performance (GPA) of undergraduate physics students studied how performance (final grade) in the mathematics course and performance in the physics course is correlated within the undergraduate physics program. The study particularly focused on the three year BEd physics program and the new harmonized BSc physics program in Bahir Dar University, Ethiopia. To what degree does a student's academic performance (GPA) in mathematics related to his/her physics score? Or how good was the mathematics GPA is predicting students' physics academic performance? A measure of this correlation is obtained by correlating course grade performance. Course grade is considered as a measure of course performance in the study. In almost all of the physics courses evaluated in the Bahir Dar University, the student's physics course grade was determined almost entirely by performance on examinations consisting primarily of physics problem solving. Thus the student's course grade is measure primarily of physics problem solving performance. Method of inquiry included grade report analysis for the three year BEd physics program students beginning in the academic year 2007/8 at the Bahir Dar University.

Specifically, aiming at answering the preliminary research question, the study explored the situations across the harmonized new undergraduate BSc physics curriculum by evaluating students' academic performance (GPA) in the mathematics and physics courses. The data for this case were also drawn from grade report analysis for students beginning in the new harmonized BSc physics curriculum in the academic year 2008/9 at the Bahir Dar University. In both BEd physics program (old curriculum) and BSc physics program (the new harmonized curriculum) the final grade of student was reported to the Registrar's office as a letter grade. An effort was made to obtain the numeric grades, but it was found to be too difficult to collect all grades from each instructor for that period of time. In order to calculate a statistical correlation, the letter grade was converted to a numeric grade by the following standard obtained from the harmonized BSc curriculum as shown in the Table II. All student records were kept confidential.

In the second phase of the study, a content analysis were employed to critically evaluated whether an apparent mismatch or relevant integration exist between the progression of the mathematics courses and the level of mathematics required to do advanced physics courses in the new, BSc Undergraduate Physics Curriculum. Evaluation research utilizes multiple sources and methods of data collection and analysis. In order to do an evaluation of a program it "should be based on the content, purpose, and outcomes of the program, rather than being driven by data collection methodologies" [10]. Therefore, data was collected from undergraduate physics program documents, the harmonized curriculum for BSc degree program in physics Ethiopia. The use of suitable information sources and types of data authorized the researcher to increase the credibility of the results. To limit the volume of data collected to a manageable level, we purposively sampled courses from the harmonized curriculum for BSc degree program in physics. Courses were stratified by the level of mathematical formalism in which the courses are shrouded. Thus, for the purpose of investigation in this paper Classical Mechanics I and Statistical Physics I courses were selected.

TABLE II. Converted grade system as utilized in the study in order to calculate a statistical correlation.

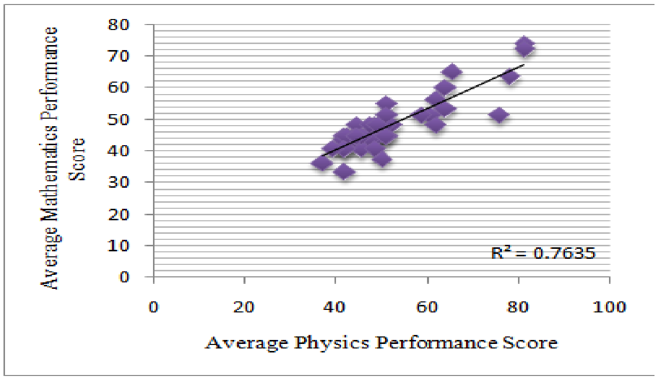
Range of Marks (100%)	Letter Grade	Converted Numeric Grade
≥ 75	A	87.5
[70 -75)	A-	72
[65 - 70)	B+	67
[60 - 65)	B	62
[55 - 60)	B-	57
[50 - 55)	C+	52
[40 - 50)	C	44.5
[35 - 40)	C-	37.5
[30 - 35)	D+	32
[20 - 30)	D	24.5
< 20	F	9.5

V. RESULTS

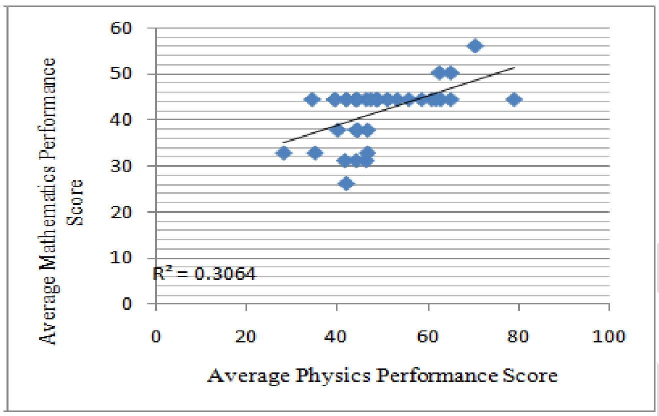
In the first phase the correlation between student final grades in mathematics and physics courses in two physics undergraduate program as well as the use of the mathematics score as a predictor for physics course score was examined. It was hoped that the results would provide valuable information, allowing the researchers to make informed evaluation and judgments concerning how good was the predictive value of mathematics score on students' physics academic performance (final grade). As well as the result would help the researcher to evaluate the form and content of the new BSc physics program with respect to the progressions of the mathematics and physics courses.

A. Correlation of Mathematics Performance with Physics Performance

The study investigates how well mathematics performances (final grades) correlate with physics performance (final grades). This is done by study focusing on the performance of 49 second year physics students at Bahir Dar University in the BEd undergraduate program and 40 second year physics students at the same University registered in the new BSc physics program. Students' mathematics performance (final grade) and physics performance were analyzed by the SPSS 11.0 and Microsoft Excel. A linear regression method was used to determine correlation between different scores. The average mathematics performance of these students was compared to their parallel physics performance score in both curricula as indicated below in Figure 1(a) and Figure 1(b).



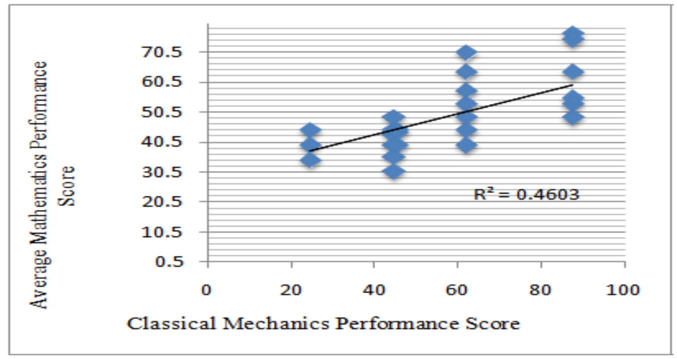
(a) *For BEd Curriculum*



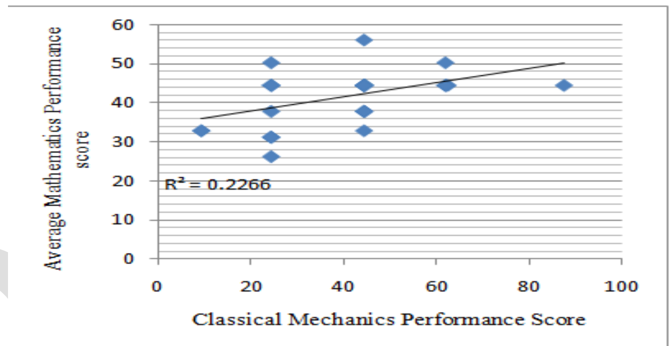
(b) *For BSc Curriculum*

FIGURE 1. Average mathematics performance score versus average physics performance score.

These average mathematics scores were then plotted for each student against their average result for their physics courses, examples of such plots are shown in Figure 1(a) for the BEd physics program and Figure 1(b) for BSc physics program. There is an amount of scatter in both sets of data and although it could be argued that there is generally a positive association between the mathematics performance score and the physics performance score for BEd physics curriculum. This could predominantly be due to those students taking more advanced physics courses that need higher level mathematics after generally performed all the required mathematics courses. A linear regression line has been fitted to both sets of data and the R^2 value, or coefficient of determination, was calculated. For the BEd physics curriculum R^2 = 0.7635 and for the BSc physics curriculum R^2 = 0.3064; this indicates a relatively good relationship between the average mathematics performance score and the average physics performance score for the BEd program. However, the result indicated a fair relationship between the average mathematics performance score and the average physics performance score for the BSc program.



(a) *For BEd Curriculum*

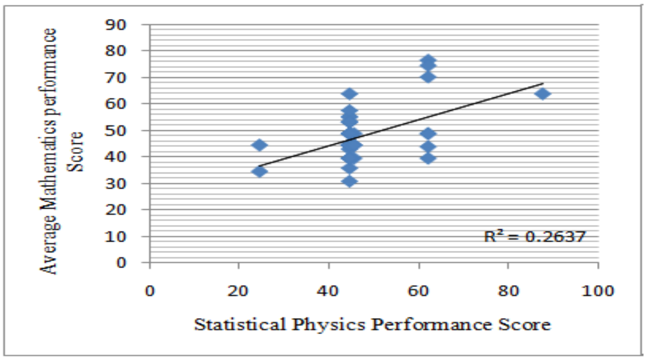


(b) *For BSc Curriculum*

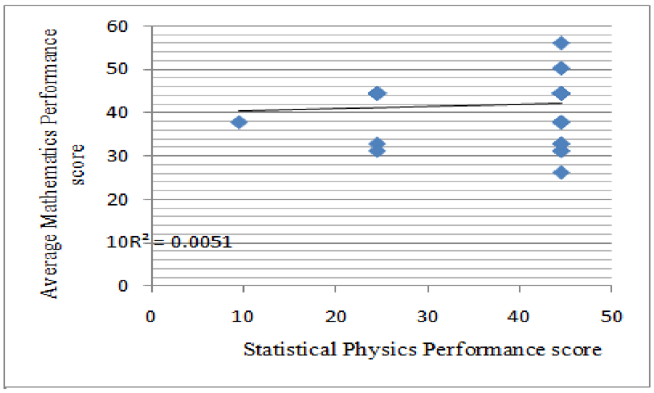
FIGURE 2. Average mathematics performance score versus classical mechanics performance score.

The correlation between the average mathematics performance score and classical mechanics performance score for BEd and BSc curriculum are shown in Figure 2(a) and Figure 2(b). There is an amount of scatter in both sets of data. However, it could be argued that there is relatively a positive association between the average mathematics performance score and the classical mechanics performance score for BEd physics curriculum. The relationships appear to be very weak for the BSc curriculum. Moreover, the plot indicates that students with greater score in average mathematics performance scored a weak result in Classical Mechanics (see Figure 2 (b)).

Correlation coefficients were also examined to determine the strength of the relationships between the average mathematics performance and the statistical physics performance (see Figure 3 (b) and (b)). Similar to the result found above, a relatively fair correlation occurred between the average mathematics course performance and statistical physics performance in the BEd physics program (R^2 = 0.2637). The strength of this relationship exceeds that of the correlation between the average mathematics performance and statistical physics performance (R^2 = 0.0051) which indicates little or no relationship.



(a) *For BEd Curriculum*



(b) *For BSc Curriculum*

FIGURE 3. Average mathematics performance score versus statistical mechanics performance score.

One important question was asked before commencing the first phase of study. That is, ‘how good was the predictive value of mathematics performance on students’ physics performance?’ This question is answered using the correlation analysis for the two subjects. The results are very consistent across the BEd physics program with fair to good correlations. Despite the limitation that the students’ scores were converted from letter grade to numeric grade which may have led to missing some of the fine details of the scores in the analysis of the results, however it indicates that the mathematics performance is a relatively moderate indicator in predicting students’ physics performance in the undergraduate physics program. This limitation may introduce bias to reduce the accuracy of the regression analysis. However, it is unlikely that the overall results or trend have been affected by the conversion. It is recommended for future study that numeric scores be used. Contrary to those positive findings in the old BEd physics program, the correlation between the average mathematics performances with physics performance was weak in the new BSc physics program particularly in statistical physics and classical mechanics performance. Moreover, this study provides some evidence that students who scored well in the mathematics courses may not perform well in the physics courses. Therefore, as discussed in the literature, the reason behind for this weak correlation may be due to the lack of students’ required and prerequisite mathematics knowledge and/or they do not know how to apply the mathematical knowledge they have learned in the mathematics classes taught by mathematician to the context of physics in the physics class.

B. Research Findings for Content Analysis of the BSc Physics program

Undergraduate physics student problems in physics using mathematics are widespread and originate from many sources [1]. The first step to bridge the gap between mathematics and physics is to recognize the barriers in the mathematics and physics curricula. In this respect, this paper tries to determine the progression of the mathematics course and the level of mathematics required of students in the department of physics at Bahir Dar University, Ethiopia. In Ethiopia, as described below, the undergraduate physics curriculum has a comprehensive list of courses in mathematics relevant to the core physics courses in the department of physics.

The core physics courses in the first and second year of the physics program at the Bahir Dar University are Mechanics, Wave and Optics, Electromagnetism, Modern Physics, Statistical Physics, Classical Mechanics I, Electronics I, Modern Optics, Quantum Mechanics I, Electrodynamics I and Nuclear Physics I. In this program, all of the mathematics topics are taught in required first and second year mathematics courses. The compulsory mathematics courses include: Calculus I, Calculus II, Mathematical Methods of Physics I, Linear Algebra and Mathematical Methods of Physics II. As introduced earlier in this paper, to limit the volume of data collected and analyzed to a manageable level, we purposively sampled only two courses (Classical Mechanics I and Statistical Physics I) from the physics program. Classical Mechanics I and Statistical Physics I are intended for students with a strong background in physics and calculus-based mathematics. In the current physics curriculum, students studying Classical Mechanics I and Statistical Physics I are after covering some prerequisite physics and mathematics courses including: Mechanics, Wave and Optics, Electromagnetism and Modern Physics, Calculus I and Calculus II in their first year (Refer to the Table I).

The Classical Mechanics I course comprises 45 lecture hours and it introduces generalized treatment of the motion of particles in various coordinate systems. It also addresses an alternative formulation of solving classical problems using Lagrange’s and Hamilton’s principles. Similarly, the Statistical Physics I course is 45 lecture hours course and it is designed to provide introductory ideas of the basic principles of statistical physics and their application. The contents included in this course are essential in understanding probabilistic nature of microscopic phenomena. A clear connection between microscopic and macroscopic interpretations of the physical systems would be established. Major topics included in the two courses as well as the required mathematical knowledge needed for solving problems in these courses are shown in Table III.

TABLE III. Major topics included in Classical Mechanics I and Statistical Physics I courses with the required level of mathematics needed.

Sampled physics course in the study	Major topics to be covered in the course	Required mathematical knowledge in the course
Classical Mechanics I	Coordinate Systems Particle Dynamics Oscillations Central Field Lagrange's and Hamilton's Formulation	Coordinate transformation, Algebra: Vectors and matrix algebra Vector calculus: time derivative of vectors, field and gradient, the divergence, circulation and the curl, the Laplacian operator, vector calculus expressions and identities Basic Calculus I and Calculus II First order differential Equations Second order differential equations Partial Differential Equations
Statistical Physics I	Features of Macroscopic system and Basic Probability Statistical Description of systems of Particles Thermal Interactions Microscopic Theory and Macroscopic Measurements Canonical Distribution	Basic Mathematics in algebra and Calculus Statistical Mathematics for Physics

Within the Classical Mechanics I, students are expected to describe base vectors and their reciprocal coordinate systems; interpret non-orthogonal base vectors orthogonal coordinates, system coordinate transformation; obtain generalized velocity and acceleration and gradient operator in cylindrical and spherical coordinates by using a range of mathematical skills indicated in Table III. Moreover, in this course, students solve problems on oscillations, stable and unstable equilibrium, one-dimensional motion of a particle in a given potential field, simple harmonic oscillations in one and two dimensions, damped oscillations, forced oscillations and resonance, oscillations in electrical circuits and rate of energy dissipation.

TABLE IV. The mathematics courses with study year/semester and major topics included.

Mathematics course	Study year/semester	Prerequisite/Co-requisite to the sampled physics courses	Topic included in the course
Calculus I	Year I/ Semester I	Prerequisite	Limit and Continuity, Derivatives, Applications of derivatives and Integrals
Calculus II	Year I/ Semester II	Prerequisite	Inverse function, Technique of integration, Indeterminate forms, improper integral and Taylor formula, Sequences and series
Mathematical Methods of Physics I	Year II/ Semester I	Co-requisite	Distribution function graphs and approximation, First and second order differential equations, Wave and Fourier analysis
Linear Algebra	Year II/ Semester I	Co-requisite	Vectors and vector spaces, Matrix, Determinant and linear transformation

They determine the Lagrangian and Hamiltonian of mechanical systems and use these functions to obtain the corresponding equations of motion. Thus a student, who has had relevant prerequisite mathematical courses shown in Table II, would be able to recognize the basic concepts of the courses like Classical Mechanics and solving problems. On the other hand, mathematical topics included in the prerequisite mathematics courses as well as in the required co-requisite mathematical courses are limited in scope and deficient in content in delivering the required knowledge.

TABLE V. Comparison of the progression of the mathematics courses and the level of mathematics required to do Physics.

Mathematics courses	Year / Semester of study	Mathematical topics included	Mathematical topics not included in the prior mathematics courses but Students needed for Solving Classical Mechanics & Statistical Physics
Calculus I Calculus II	Year I/Semester I Year I/Semester II	Limits and continuity Derivatives Applications of derivatives Integrals Inverse functions Techniques of integration Indeterminate forms, improper integrals and Taylor's formula Sequence and series	Matrix Algebra Vector Calculus Time derivatives of vectors Fields and the Gradient The Divergence Circulation and the Curl The Laplacian operator Vector Calculus Expressions and Identities Partial Differential Equations (PDEs) Probability Statistics for physics
Mathematical Methods of Physics I	Year II/Semester I	Distribution Functions Graphs, and Approximations First-Order Differential Equations Second Order Differential Equations Waves and Fourier Analysis	
Linear Algebra	Year II/Semester I	Vectors Vector Spaces Matrices Determinant Linear Transformations	

The mathematical knowledge students' gain from both prerequisite and co-requisite courses are shown in Table IV.

For example, as indicated in Table IV, only the basic concepts and techniques of the differential and integral calculus is required from students for Calculus I; where as in Calculus II topics that covers inverse functions; techniques of integration and focusing on trigonometric substitution and partial fractions; sequences and series; and power series are included. Even though the mathematical topics included in Mathematical Methods of Physics I and Linear Algebra seem important for solving problems in Classical Mechanics, they are deficient in content and exclude compulsory topics essential for Classical Mechanics. Topics such as vector calculus: time derivative of vectors, field and gradient, the divergence, circulation and the curl, the Laplacian operator, vector calculus expressions and identities as well as partial differential equations are not included in both the prerequisite and co-requisite mathematical courses in the curriculum. Although vector spaces and matrix algebra are included in the Linear Algebra course, it appears later in the course. However, these topics are important at the start of Classical Mechanics. Moreover, probability function is relevant for solving problems related with Statistical Mechanics with no reason the topic is neglected in the prerequisite mathematics courses.

In general, as shown in Table III and Table IV, the study revealed that a number of mathematical topics, which are relevant for solving problems in Classical Mechanics, have not been considered during the organization of the undergraduate physics curriculum. As described in Table III, major portions of the Classical Mechanics require a number of mathematical techniques. However, in the undergraduate physics curriculum these topics are considered as advanced and are presented later in the study year. In order to look for the apparent mismatch among courses in the undergraduate physics program, a comparison of the progression of mathematics courses and the level of mathematics required to do Classical Mechanics I and Statistical Physics I is presented in Table V.

VI. DISCUSSIONS AND CONCLUSIONS

In the new undergraduate physics program, physics students generally take Classical Mechanics I and Statistical Physics I courses in the first semester of their second year. As shown in Table V, these courses use general vector calculus, the gradient, the divergence circulation and the curl, Partial Differential Equations (PDEs) and the probability function to solve problems included in these courses. However, for example, essential topics in mathematics like vector calculus and partial differential equations are not taught until the end of the second year first term. On the other hand the Classical Mechanics I course, which extensively make use of these mathematical topics, begins in the second year first term. Thus, as presented in Table V, it is evident that some fundamental mathematical techniques are lacking in the physics courses, leading to great difficulties with solving problems in these physics courses. To summarize these obvious mismatches that exist between the progression of the mathematics courses and the level of mathematics required to do physics in a single sentence, we could say: 'Mathematicians teach algebra; physicists do geometry.' If mathematicians and physicists speak different languages, characterized by algebra and geometry respectively, then students appear to have trouble with the mathematics in their physics classes. Consequently, they either hate mathematics in physics or fear it. Tertiary level students' success or failure in physics is dependent on more factors than simply knowledge of the subject. However, research has shown that comprehending the required mathematics is important for success in physics, and a good background is an indication of success in physics [8].

Therefore, this investigation resulted in the identification of apparent mismatches in the physics program, leading to recommendations for incorporating key mathematical topics into the physics courses, curriculum modification and/or development of bridging materials. It is further recommended that physics department staff take a small amount of time in their lectures to revisit the type of mathematics used, and in particular, to tie the mathematical topics to the appropriate physical problems in the application at hand. Our findings indicate that it would be beneficial to further investigate the problems in this area. Particularly, to explore what students are supposed to be doing mathematics in their mathematics class and what their physics class expect them to do regardless of the required and prerequisite mathematical knowledge.

REFERENCES

[1] Redish, F. E., *Problem Solving and the Use of Math in Physics Courses*, Invited Talk, Proceedings of ICPE Delhi (2005).

[2] Shallcross, E. D., Walton, G., *What's in a grade? The real meaning of mathematics grades at GCSE and A-Level*, the Higher Education Academy Physical Sciences Centre in association with πCETL, The Physics Innovations Centre for Excellence in Teaching and Learning, (2007).

[3] Steinberg, R. N., Saul, J. M., Wittmann, M. C., Redish, E. F., *Student difficulties with math in physics: Why can't students apply what they learn in math class*? 113th AAPT National Meeting, College Park, MD (1996).

[4] Tuminaro, J., *A Cognition framework for analyzing and describing Introductory Student's use and understanding of Mathematics in Physics*, Unpublished doctoral dissertation, University of Maryland, Physics Department College Park, Maryland, USA (2004).

[5] Tuminaro, J., & Redish, E. F., *Elements of a cognitive model of physics problem solving: Epistemic games*, Physical Review - Physics Education Research **3**, pages? (2007).

[6] Schalk, P. D., Wick, D. P., Turner, P. R. and Ramsdell, M. W., IMPACT: *Integrated Mathematics and Physics Assessment for College Transition*, TX, 39th ASEE/IEEE Frontiers in Education Conference, October 18 - 21, San Antonio (2009).

[7] Dray, T. D., Corinne, A. and Edwards, B., *Bridging the Gap between Mathematics and Physics*, APS Forum on Education, (2004).

[8] Boniolo, G. and Budinich, P., *The role of mathematics in physical science and Dirac's methodological revolution*, (Springe, Printed in the Netherlands, 2005).

[9] Pospiech, G., *A view on the use mathematics in physics lessons of lower secondary school*, A paper presented at the European Science Education Research Association 2009 Conference, Istanbul, Turkey, (2009).

[10] Lapan, S. D., *Evaluation studies. In K. deMarrais & S. D. Lapan (Eds.), Approaches to research: Methods of inquiry in education and the social sciences*, (Mahwah, Lawrence Erlbaum, New Jersey, 2004), pp. 235-248.