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How to Enlarge the Scope of the Curriculum Integration of Mathematics and Science (CIMAS): A Delphi Study

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Studies have not yet consented whether integrating mathematics into science would enhance students' learning or confuse their understanding of abstract mathematical concepts. In spite of the social need for solving social-scientific problems with multiple facets, there has not been a holistic integration model of the disciplines. Hence, this study aims to propose a theoretical model for curriculum integration of mathematics and science (CIMAS) and to examine experts' opinions about its educational perspectives. The model captures appropriate topics, needs (pedagogical, motivational, and societal), and constraints. In spite of the small size of participants—23 mathematics educators in Ankara, their diverse integration examples reached to the conclusion that all units in the Turkish mathematics curriculum can be integrated with physics, chemistry, or biology (e.g., derivative with linear velocity, ratio with chemical mixture, and probability with genetics), while identifying the most number of examples with physics topics. The expert responses consistently clarified that CIMAS would enhance mathematics education for the pedagogical, motivational, societal, and other needs. However, the integration was also perceived to associate with obstacles with teachers, curricula, and facilities for effective implementation. Lastly, this study further presents a key discussion on how to enlarge the scope of CIMAS in terms of collaboration among mathematics educators.

Keywords: Mathematics education, science education, CIMAS, integrated approach, multidisciplinary approach

INTRODUCTION

In the twenty-first century, students are required to get used to debating multidisciplinary problems such as restricting carbon dioxide emissions in undeveloped or developing countries, or locating a nuclear or disposal facility among local areas. These social-scientific issues should be considered in multiple perspectives that integrate different disciplines. In this light, resolving the gap between the current curriculum with its practice in schools and the expectation from social needs demands empirical studies on curriculum integration (Numanoğlu, 1999). Until the 20th century in education, the concept was not frequently practiced in secondary curricula, despite its long history (Klein, 1990). At the end of the century, curriculum integration emerged in K-12 education, addressing innovative curriculum

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State of the literature

- Although scientific and mathematical concepts are conceptually interwoven and feasibly complementary to each other, school mathematics is still detached from other disciplines and real life.
- The most recent mathematics curricular such as the Common Core State Standard for mathematics in the U.S. address mathematical practices for integrating it with science curriculum.
- This study aims to empirical evidence on how to integrate mathematics and the science disciplines, and on the optimal sub-concepts for integration.

Contribution of this paper to the literature

- There exist the frequently employed topic matches for curriculum integration: derivative with linear velocity in physics, ratio with chemical mixture in chemistry, and probability with genetics in biology.
- The CIMAS model describes that the curriculum integration would enhance mathematics education for the pedagogical, motivational, societal, and other needs.
- The open-ended responses clarify that every mathematics unit could be integrated with at least one of the three branches of science in a form of student inquiry activities, problem solving, or introductory examples.
- Ironically, 70% of the experts still answer that the integration would not be applicable to each of mathematics topics.
- Thus, to combine such discrete ideas of the curriculum integration, an effective collaboration is required.

designs to link more than one discipline and to integrate units, themes, and educational objectives (Klein, 2005). In the globalizing world, many social-scientific issues and conflicts of interest are considered through an interdisciplinary or multidisciplinary approach that coordinates information, concepts, and ability by practicing different disciplines (Balay, 2004).

In practice, science and mathematics are not only conceptually interwoven but also feasibly complementary to each other. Curriculum integration across these disciplines was claimed to relate to real world applications and motivate student learning (Frykholm & Glasson, 2005). Mathematics supported by scientific concepts was claimed to increase students' understanding of nature (Kleiman, 1991). According to Coştu et al. (2009), students in Turkey believe that receiving information about why they need to learn mathematics and how it is used in natural science or society would be beneficial and motivational. These studies addressed the needs of constructing relations between mathematics and science subjects in high schools, and accordingly, developing an integrated curriculum and textbooks. Nevertheless, school mathematics still seems detached from other disciplines and real life. It is often isolated within its own traditional textbooks, tests, and instructions different from many other subjects. Curriculum integration is not appreciated as much as it should be, which is known as one of the major curriculum issues in Turkey (Paykoç et al., 2004). It is noticeable that the most recent Common Core State Standard for mathematics education in the U.S. includes student practices such as 'M4. Model with mathematics', 'M2. Reason abstractly and quantitatively', 'M3. Construct viable arguments and critique reasoning of others', and 'M5. Use appropriate tools strategically' when it comes to the science integration (NGSS Lead States, 2013). It warrants empirical studies on what topics from both disciplines should be converged for optimum learning practices. Hence, this study aims to provide mathematics educators with a piece of empirical evidence on how to integrate mathematics with the science disciplines.

LITERATURE REVIEW

Disciplinary approaches

As Piaget proposed, a specific discipline such as a classic mathematics has long been taught based on its own background knowledge, techniques, ways, and content areas (as cited in Jacob, 1989). Besselaar and Heimeriks (2001) defined *the disciplinary approaches* as "It is 'normal problem solving' within a 'paradigm', and with hindsight, we can define the boundaries of disciplinary fields." (p. 2). Therefore, in this study, a disciplinary approach is referred to as a description of knowledge, skills, problems, methods, and studies that is exclusively related to one academic area.

Integrated approaches

On the other hand, certain comparative ideas, data, procedures, and methods should be combined from various disciplines so that their interactions are employed for solving practical problems (Besselaar & Heimeriks, 2001). When a teacher deigns and implement learning activities across more than one concept, such curriculum integration should be coherent. *Integrated approaches* is defined as an instructional approach to contain both integration-based activities and discipline-based activities (Lonning & DeFranco, 1997). The following metaphor summarizes society's response to the fragmentation as a need for a integrated approach, "A doctor cannot be trained only in the psychology and biology of the body; a doctor treats the whole human being." (Jacob, 1989, p. 6). The approach supports such interactions between disciplines that concern their common problems and issues that relate to natural concepts and social phenomenons. Interdisciplinary and multidisciplinary approaches are two types of integrated approaches.

Interdisciplinary approaches are characterized to be more 'thematic'. It is defined as a curriculum understanding that intentionally applies to methodology and terminology that involve more than one area of science. It examines a specific topic, problem, issue, or experience, varying from personal issues of identity to abstract intellectual questions (Klein, 2006). An interdisciplinary course can be considered as application-oriented. This approach, in contrast to other approaches, provides more interwoven connections between subjects (Jacob, 1989). Discovering theoretical knowledge about nature within a dominant disciplinary field is not considered as an aim of an interdisciplinary approach. Rather, studying applications as productions of knowledge is its main interest. In an interdisciplinary approach, various organizational structures, problems, and researches are involved. This approach aims at using knowledge for societal developments beyond listing segmented knowledge (Gibbons, Limoges, & Nowotny, 1997), by transferring instructional methods from one discipline to another (Besselaar & Heimeriks, 2001; Nicolescu, 1999). In higher education, 'physical mathematics' and 'biomathematics', which seek to define their unique research identities, are called to be examples of interdisciplinary approaches.

Multidisciplinary approaches are stated as "in multidisciplinary research, the subject under study is approached from different angles, using different disciplinary perspectives. However, neither the theoretical perspectives nor the findings of the various disciplines are integrated in the end." (Besselaar & Heimeriks, 2001, p. 2). Instead, this approach concerns a main learning topic interpreted in terms of more than one disciplines. While this approach deepens students' understanding of a main discipline, it is limited to a framework of disciplinary research (Nicolescu, 1999). That is, a multidisciplinary approach overflows disciplinary boundaries, while its goal remains in a dominant disciplinary research. In this approach, it is not required to combine disciplines throughout. Rather, disciplines are blended in a sequential or juxtaposed mode, listing discrete and encyclopedic knowledge (Klein, 2006). Generally, a multidisciplinary curriculum supports disciplines through providing different perspectives, without universally integrating each principle. Students taught in this approach would be asked to view the lower degree of integration without studying a direct assembly of knowledge.

Models for integration

There is more than one way to integrate curricula. Fogarty (1991) categorized different integration models as sequence, shared, webbed, threaded, and integrated (Figure 1). Fogarty likens the sequence model to eyeglasses. Two different disciplines are depicted as two glass lenses that are connected to each other with a universal framework. For example, the biology unit, genetics, and the mathematics unit, probability might be taught in separate or linked classes when designed in the sequenced model. The shared model is likened to binoculars. Similarly, this model concerns two separate disciplines. Different from the eyeglass model, it captures a focused overlap. Two disciplines interpret their common unit, so much so that cooperative work between teachers is the key difference between the two models. The webbed model is likened to a telescope that supplies a broader view of curriculum integration wherein various elements are webbed to a theme. In this model, one dominant theme is interpreted by multiple heterogeneous disciplines. The threaded model is depicted as a magnifying glass that helps to enlarge concepts of all involved disciplines. This model supports students to improve their social, reading, thinking, and prediction skills in sequence. Lastly, the integrated model is likened to a kaleidoscope that symbolizes overlapping topics and concepts through an interdisciplinary approach (Fogarty, 1991; Kysilka, 1998).

In specific, there exist models capturing science and mathematics curriculum integration. Huntley (1998) divided curriculum integration into five categories: mathematics for the sake of mathematics, mathematics with science, mathematics and science, science with mathematics, and science for the sake of science. Similarly, Lonning and DeFranco (1997) established another model for mathematics and science integration. This continuum model of curriculum integration presents five varied steps: independent mathematics, mathematics focus, balanced mathematics and science, science focus, and independent science. The independent mathematics and the independent science models include integration only within disciplines. In the mathematics focus and the science focus, science or mathematics is placed on the focus, while other discipline supports the focus. The role of disciplines is equally distributed in the balanced mathematics and science.

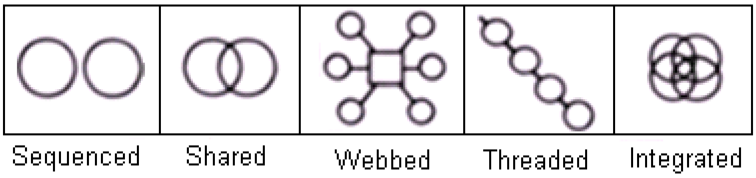

Figure 1. Five ways to integrate curriculum across multiple disciplines (Fogarty, 1991)

Needs for curriculum integration

To design a curriculum to be more interdisciplinary, it is required to discuss the curriculum development process that restructures the domain of mathematics knowledge into mathematics education at K-12 levels. Robitaille and Dirks (1982) modeled the development of a mathematics curriculum; their model consists of *pedagogical, motivational (psychological),* and *societal (sociological) needs*. In terms of the three needs, this study addresses the reason curriculum integration is demanded in the modern curriculum.

Pedagogical needs (PN). A integrated approach is claimed to foster cooperation of teachers for a more effective learning environment (Wicklein & Schell, 1995). As approached in a form of the integration that offers connections between heterogeneous disciplines, an integrated curriculum becomes more relevant to students (Jacobs, 1989). Curriculum integration provides students with opportunities for intellectual curiosity, critical thinking, and problem solving skills with real world applications (Loepp, 1999; Wicklein & Schell, 1995). Curriculum integration has been determined by implementing these constructivist instructions, rather than by memorizing facts or following prescribed instructions (Kaya et al., 2006; Klein, 2005; Loepp, 1999).

Curriculum integration of mathematics and science had positive effects on students' achievements, although integrated disciplines sometimes demanded more efforts in designing and teaching (Hurley, 2001; Mupanduki, 2009). Such integration would not only facilitate a notable achievement in mathematics, but also provide recognizable evidence on students' achievement in science. For example, mathematics and science integration was determined to improve performance of students in open-ended problem-solving tasks, suggesting that the integrated curriculum enhanced students' ability to understand real-life problems (Cosentino, 2008). The final science examination scores among the sample students were examined to be higher, when they were taught in conjunction with mathematics. In this light, Klein (2005) emphasized that integrating disciplines would develop the four student abilities:

> *the ability to ask meaningful questions about complex issues and problems; the ability to locate multiple sources of knowledge, information, and perspectives; the ability to compare and contrast them to reveal patterns and connections; the ability to create an integrative framework and a more holistic understanding (p. 10).*

Motivational needs (MN). One of the most frequent student complaints about learning mathematics is that mathematics classes are disconnected from their real world (Jacobs, 1989). The questions include 'Why do we need to learn mathematics?' and 'Where will we use it?' Without answers to these questions, it might result in the lack of motivation in their learning environment. They often have difficulties understanding mathematics when textbooks are isolated from its applications. Therefore, applicable aims of learning scientific subjects should be clarified to students, as students encounter difficulty in learning mathematics and science separately. In this point of view, an integrated curriculum should involve real life situations, so as to relate to multiple disciplines and eventually to promote students' motivation (Hoaclander, 1999).

For example, Cosentino (2008) stated that integration of science and mathematics, which contained more abstract concepts than other disciplines, provided students with motivation for applications of the concepts to be learned. Since the mathematics and science disciplines were complementary, their collaborative project provided situated contexts for learning and helped motivate students (Frykholm & Glasson, 2005). In other words, students could enhance their learning motivation, when they developed awareness of the necessity and the importance of mathematics in real life (Loepp, 1999).

Societal needs (SN). The growth of knowledge demands a multidisciplinary approach in mathematics education in this information era (Jacobs, 1989; Kaya, Akpınar, & Gökkurt, 2006). In a societal context, an educational system is planned to fulfill expectation of a society. Hence, it has been claimed that development of modern society requires connecting different disciplines. Problems that citizens, workers, or family members face are not always comprehensible based on textbooks in a single discipline. Rather, integrative thinking provides people with knowledge for unexpected situations (Klein, 2005). Especially, mathematics and science integration has a social significance in today's information age. It is claimed that success in mathematics and science is regarded as an indicator of an effective education system and an indicator of development of a society (Cosentino, 2008).

Constraints on implementation

There exists more than one definition for curriculum integration; therefore, such multitude of the approaches might cause difficulties and challenges, when designing a program that integrates science and mathematics (Cosentino, 2008). Planning lessons for integrated knowledge requires responsibility of teachers and administrators. Wicklein and Schell (1995) determined one of the factors that had influenced a success of their multidisciplinary integration project was the coordination effort between schoolteachers and administrators. Autonomy to reorganize class administration such as teaching loads, class periods, and student scheduling had been given to the schools as a control group, which enabled them to be successful in implementing their curriculum integration.

Other challenges for curriculum integration could emerge among teachers. They need to become more skilled and knowledgeable about multiple subjects (Loepp, 1999). Within all integrated areas, teachers are expected to be capable of combining different subject areas, and using a diversity of learning and teaching techniques. For example, using technology for graphical presentations and correlational analysis in mathematical modeling of physical natures or real life situations could be one of the essential requirements. For students, curriculum integration could result in their limited learning (Wicklein & Schell, 1995). They might not sustain their focus on abstract concepts in multifaceted lessons. In order to prevent it, objectives of a multidisciplinary lesson should be coherently related to a dominant topic that is clearly instructed to students. Lastly, lack of resources such as planning time, supports for schoolteachers, instructional guides, and assessment tools is known as another obstacle to implementation of integrated knowledge (Cosentino, 2008; Satchwell & Loepp, 2002).

Framework model: CIMAS

This study addresses Fogarty's (1991) integration model 'webbed', wherein mathematics is located in the center and science is placed to develop the meaningful understanding of mathematics. This is in line with the models, Huntley's (1998) 'mathematics with science' and Lonning and DeFranco's (1997) 'mathematics focus', as these integration models find their relevance in a 'multidisciplinary approach'. This approach provides students with sequential topics to support the mainly focused subject—mathematics. Students need to comprehend the junctions of each overlapped topics through building the knowledge hierarchy of the dominant (mathematics) and the applied (science) disciplines. In addition, the literature review shows ways to understand different needs of integrated disciplines. The pedagogical, motivational, and societal needs would help comprehend integrated knowledge from different perspectives. Lastly, attitudes from teachers, students, and administrators would highlight obstacles and disadvantages, while applying curriculum integration. Based on the theoretical discussion, this study derives a model depicting the curriculum integration of mathematics and science (CIMAS) in secondary curricula (see Figure 2).

Research questions

In practice, although students are expected to develop problem-solving skills through the constructivist approaches and the curriculum integration, they still feel unsure about understanding mathematics. That is because current textbooks and teaching techniques are not connected with real life applications. It is believed that a curriculum should be designed to be more relevant to everyday situations with mutual connections between subjects (Hoaclander, 1999; Wicklein & Schell, 1995), which is not prevalent in Turkey. Another contextual issue that puts a limit on the curriculum innovation is the university entrance exam that is known as a strong educational factor not only in Turkey but also in many Asian countries such as Korea, Japan, and Taiwan (Guo, 2005). The centralized exam has been one of the constraints for achieving a desired learning and teaching environment, as it mostly demands a narrowerer aspect of learning: memorizing discrete concepts and facts from separate disciplines (Altun, 2006).

In theoretical discussions on curriculum integration, "There continues to be a lack of consensus regarding the definition of integration." (Czerniak, 2007, p. 553). Much previous research fails to observe consistent effects of curriculum integration, overlooking a holistic influence of curriculum integration. A consented model should not only demonstrate positive learning achievement from curriculum integration, but also details of its obstacles and disadvantages. Considering both practical and theoretical discussions of the curriculum integration of mathematics and science (CIMAS), this Delphi study aims to examine academics and mathematics teachers' consensus on how to integrate science into the mathematics curriculum in the Turkish context, resolving the research questions shown below:

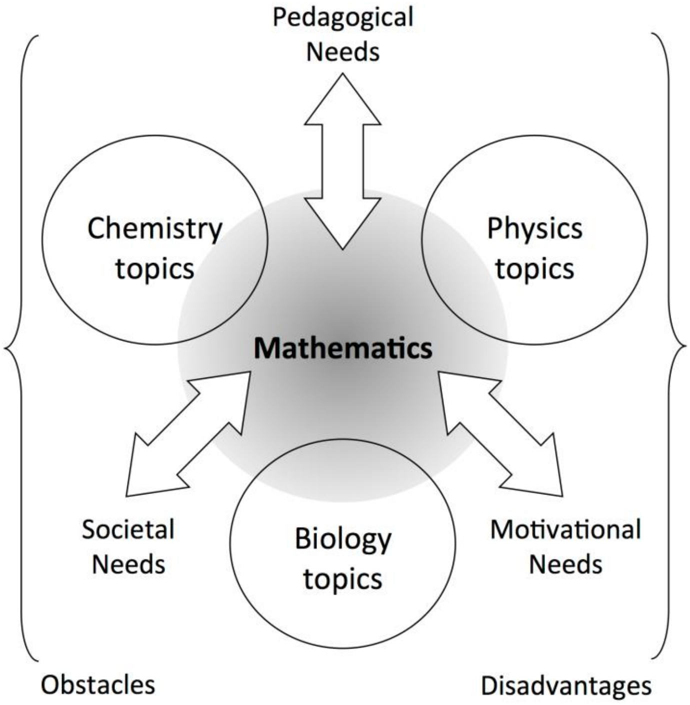

Figure 2. A model of the curriculum integration for mathematics and science integration (CIMAS)

Research Question 1: What topics are appropriate for curriculum integration of mathematics and science (CIMAS)?
Research Question 2: How do the experts perceive the needs (pedagogical, motivational, and societal) of CIMAS?
Research Question 3: How do the experts perceive the constraints (obstacles and disadvantage) of CIMAS?
Methods

Research design: Delphi study

Developed by the Rand Corporation in the 1950s, the Delphi technique is an expert survey for "systematic solicitation and collation of judgments on a particular topic through a set of carefully designed sequential questionnaires interspersed with summarized information and feedback of opinions derived from earlier responses" (Delbecq, Van de Ven, & Gustafson, 1975, p.10). Since the Delphi technique consists of plural rounds such as open-ended and Likert-scale surveys, the method is considered as both a qualitative and quantitative approach. Time management is one important consideration of this method because late responses from certain panel members might slow down its entire process (Wiersma & Jurs, 2009). In this study as detailed in Table A1, Appendix, two rounds of surveys were compiled and administrated to ask questions related to appropriate topics of integration, needs, and constraints of CIMAS. An online address leading to the survey was sent to the panel members via emails. When a week had passed since the first email, they were reminded by a phone call to complete the survey. All responses were obtained online.

Participants

Since a Delphi study required explicit criteria for choosing a panel, the participant experts of the panel members in this study were chosen among university academics and schoolteachers who were knowledgeable and experienced in teaching mathematics. Sampled in Ankara, the capital of Turkey, they were 16 mathematics teachers from two private schools with their three or more years of experience, and 7 university academics working in institutions of mathematics education. For balancing the portion between schoolteachers and university academics, email invitations of the 1st-round survey were sent to all 44 academics with the doctoral degree in this region. Five academics refused to participate in this Delphi study, replying that they did not have relevant knowledge about the high school mathematics curriculum. The 2nd-round survey was complied based on responses from the 1st-round survey. All participants who had attended the first round responded to the second round as well (N = 23).

First-round open-ended survey

To collect open-ended responses about the implementation process of curriculum integration, the experts were asked to response their opinions about possible topics, needs, and constraints of CIMAS. For this aim, the 1st-round survey asked five questions as below:

(Topics) Q1-Q3. What are the appropriate topics in the high school curriculum for integrating mathematics with physics/chemistry/biology? Please explain it with examples.
(Needs) Q4. What could be the possible needs of integration of mathematics with science for students' learning? Please explain your opinions with examples.
(Constraints) Q5. In Turkish context, what could be the possible disadvantages and obstacles of science to mathematics that affect students' learning process? Please explain your opinions with examples.

To avoid using improper wording or ambiguity in the questions, a pilot-test was conducted among two academics and five graduate students prior to the actual survey. In this way, validity of the questions was ensured. Time needed to respond the survey was found to be approximately 45 minutes.

Second-round Likert-scale survey

All 54 responses from the questions Q4 of the 1st-round survey were analyzed to develop the 2nd-round Likert scales. These statements were divided into four categories according to the literature review: pedagogical needs (PN), motivational needs (MN), societal needs (SN), and other needs (ON). According to this theoretical criterion, similar opinions were combined into a category. At the end of this analysis, 6 opinions were coded for MN, 3 opinions for PN, 4 opinions for SN, and 3 opinions for ON. These 16 items about the needs were asked by 3-choice Likert scales: *agree, disagree*, and *no opinion*. In the same method, the experts' 47 responses of the constraints asked by Q5 were analyzed to identify commonalities. These statements were categorized into 4 teacher-related constraints (TC), 4 curriculum-related constraints (CC), 4 facility related constraints (FC), and 5 student-related constraints (SC). The identical 3-choice scale asked each of these 17 items about the constraints.

RESULTS

Appropriate topics for CIMAS

In the open-ended question Q1-Q3, the experts reported science topics shown in example uses of their integration with mathematics. Table 1 and Table 2 respectively summarize the responses with the categorization of mathematics or science topics.

Topics for physics integration. Derivative (f = 16) was answered as the most perceived topic in high school mathematics for CIMAS. This topic was combined with linear velocity and acceleration in physics, which explains the relation that acceleration is defined as a derivative of linear velocity. As integral is the reverse process of derivative, 12 experts gave integral as another common topic. Trigonometry (13) was ranked after derivative. Trigonometric ratios and periodic functions were specifically combined with optics, projectile motions, and force in the experts' open-ended responses. Ranked after them, functions (7), equations (6), vectors (6), numbers (5), limit (5), logarithm and exponential functions (3), and analytic geometry for line (3) were also responded as being appropriate topics to the integration by the participants.

Table 1. Frequency of mathematics topics for science integration

Discipline area	Mathematics topic (frequency)
Mathematics for physics	Derivative (16), Trigonometry (13), Integral (12), Functions [a] (7), Equations [b] (6), Vectors (6), Numbers [c] (5), Limit (5), Logarithm/Exponential functions (3), Analytical geometry of a line (3), Graphs (2), Complex numbers (2), Inequality (2), Area (2), Volume (2), Triangles (2), Ratio and proportion [d] (2), Matrices (2), Geometry Of translation (1), Statistics (1), Periodic functions (1), Differential equations (1), Logic (1), Coordinate plane (1), Motion problems (1),
Mathematics for chemistry	Ratio and Proportion (12), Logarithms/ Exponential function (12), Numbers (10), Equations (6), Derivative (3), Graphs (3), Geometry in 3-D (3), Function (2), Polar coordinates (1), Units (1), Angles (1), Measurements (1), Inequality (1), Statistics (1), Operations (1), Integral (1), Analytical geometry for lines (1), Logic (1)
Mathematics for biology	Probability (13), Logarithm/Exponential function (10), Statistics (9), Derivative (5), Numbers (5), Graphs (4), Equations (3), Sets (2), Combination (2), Percentage calculation (2), Function (2), Permutation (1), Ratio and proportion (1), Units (1), Scientific form (1), Operations (1), Integral (1), Logic (1), Series (1)

Note. [a]*Functions: 1st and 2nd degree functions;* [b] *Equations: 1st and 2nd degree equations;* [c] *Numbers: exponential numbers, square roots, very small and very large numbers, types of numbers;* [d] *Ratio and proportion: mixture problems*

Topics for chemistry integration. Ratio and proportion (f =12), and logarithms and exponential functions (12) were answered as the most appropriate integration topics in high school mathematics. In the experts' open-ended responses, ratio and proportion were commonly associated with mixture problems, compounds, and equilibrium in chemical reactions. In addition, logarithms and exponential functions were considered together with the *ph* measurement in acid-base and the half-life of an atomic nucleus in radioactivity. Ranked after them, numbers such as exponential numbers and radical numbers in scientific notations were given as examples of curriculum integration. They were integrated with chemical reactions, Avogadro numbers, compounds, and mixtures. In addition to these topics, equations (6), derivative (3), graphs (3), and 3-D geometry (3) were considered as suitable topics by the academics and teachers.

Topics for biology integration. Probability (f =13) was answered as the most perceived topic in high school mathematics for integration with biology. In the experts' open-ended responses, the examples of probability were integrated with genetics, which explains combinations of maternal and paternal chromosomes. It was followed by logarithms and exponential functions (10). Especially, these functions and their graphs were associated with the increase or decrease in population of a region. In this light, statistics (9) was also another common response for genetics. Along with the three highest ranks, derivative (5), numbers (5), graphs (4), equations (3) were reported as other suitable topics by the academics and teachers.

Chi-square test. Chi-square test was conducted to determine whether there was a significant difference between expected frequencies and the observed frequencies of the example topics in physics, chemistry, and biology. According to the analysis, the topics in each three science disciplines were not equally distributed, $\chi2$ (2) = 6.70, $p < .05$. Physics had the most topics (f = 23) that were identified for mathematics integration more than biology and chemistry topics.

Consensus of the needs for CIMAS

Conducted after a month since the 1st-round survey, all experts answered the 2nd-round survey by the 3-choice Likert scale. According to the quantitative data, Figure 3 was drawn to illustrate the degree of agreement on each statement. In the Likert-scale survey, 16 open-ended responses concerning the needs of CIMAS were categorized into 3 pedagogical needs (PN), 6 motivational needs (MN), 4 societal needs (SN), and 3 other needs (ON). Each item and category was renumbered to highlight the degree of experts' consensus.

The experts reached the highest agreement on the pedagogical needs of CIMAS, M = 90%. This category of the needs contains the open-ended statements asking whether CIMAS promotes permanent and conceptual learning, and cognitive skills. The motivational needs are ranked in the second place, M = 87%. This category of the needs contains the statements concerning concrete everyday mathematics, science and technology development, and students' intrinsic motivation and positive attitude. The societal needs followed after them, M = 82%. This category of the needs contains the statements concerning students' everyday life, their future careers, and their necessary science skills. Lastly, three statements were added to the other needs, M = 70%. This category of the needs discusses whether CIMAS helps interest students and saves time in teaching.

Table 2. Frequency of science topics for mathematics integration; the most topics were referred from physics integration; $\chi2$ (2) = 6.70, $p < .05$

Discipline area	**Science topic (frequency)**
23 physics topics	Linear velocity (12), Acceleration (11), Force (5), Projectile motions (5), Motion (5), Optics (5), Free Fall (4), Mechanics (4), Work (2), Circuits (2), Electric (2), Heat (2), Vectors (2), Kinetic energy (1), Harmonic motion (1), Angular velocity (1), Pressure (1), Simple machine (1), Moment (1), Magnetic (1), Waves (1), Sound intensity (1), Mechanics of quantum (1)
12 chemistry topics	Mixture (7), Chemical reactions (5), Acid-Base (5), Radioactivity (4), Organic chemistry [a] (3), Compounds [b] (3), Experiments [c] (2), Heat in chemical reactions [d] (2), Oxidation (1), Avogadro number (1), Physic-chemistry (1), Volume (1)
10 biology topics	Genetics [e] (11), Population [f] (9), Segmentation (3), Experiments (2), Properties of creatures (1), Dose of medicine (1), Radiocarbon dating (1), Pollution (1), Recovery time (1), Rate of growth (1)

Note. [a] *Organic chemistry: structures of molecules, angles between chemical bonds;* [b] *Compounds: ratio and proportion, distance between atoms;* [c] *Experiments: representation of results;* [d] *Heat in chemical reactions: Hess principle;* [e] *Genetics: Pedigree chart, DNA graph, Mendel-cross breeding;* [f] *Population: increase or decrease in the amount of bacteria, number of people, reproductively*

Consensus of the constraints on CIMAS

The 17 open-ended responses about constraints on CIMAS were asked in the Likert scale under the four categories: 4 teacher-related constraints (TC), 4 curriculum-related constraints (CC), 4 facility-related constraints (FC), and 5 student-related constraints (SC), as shown in Figure 4.

The experts reached the highest consensus of the teacher-related constraints, *M* = 84%. This category of the constraints contains statements that teachers might lead effective teaching, they might not communicate with colleagues, they have little time, and the teacher-training program is not ready for CIMAS. The curriculum-related constraints were placed in the second rank, *M* = 71%. This category of the constraints includes statements that CIMAS might use time ineffectively, the curriculum would be problematic, newly added topics would over-occupy class schedules, and it might not support the university entrance exam. The facility-related constraints followed them, *M* = 66%. This category of the constraints mostly states the lack of resources. Lastly, the student-related constraints present the least consensus, less than half, *M* = 17%. This category of the constraints presents the uncertain disadvantages of CIMAS, in terms of hindrances to students' learning.

Of note is that interpretation of the constraints should be separately conducted into the first three as obstacles of CIMAS implementation and the last as disadvantages of CIMAS. To effectively implement CIMAS in schools, the experts perceived that these obstacles related to teachers, curricula, and facilities (66-84%) should be diminished. It can also be inferred that the current efforts of implementing CIMAS has not been effective due to these obstacles. However, when asked about the possible disadvantages as results of implementing CIMAS, the low consensus rate (17%)

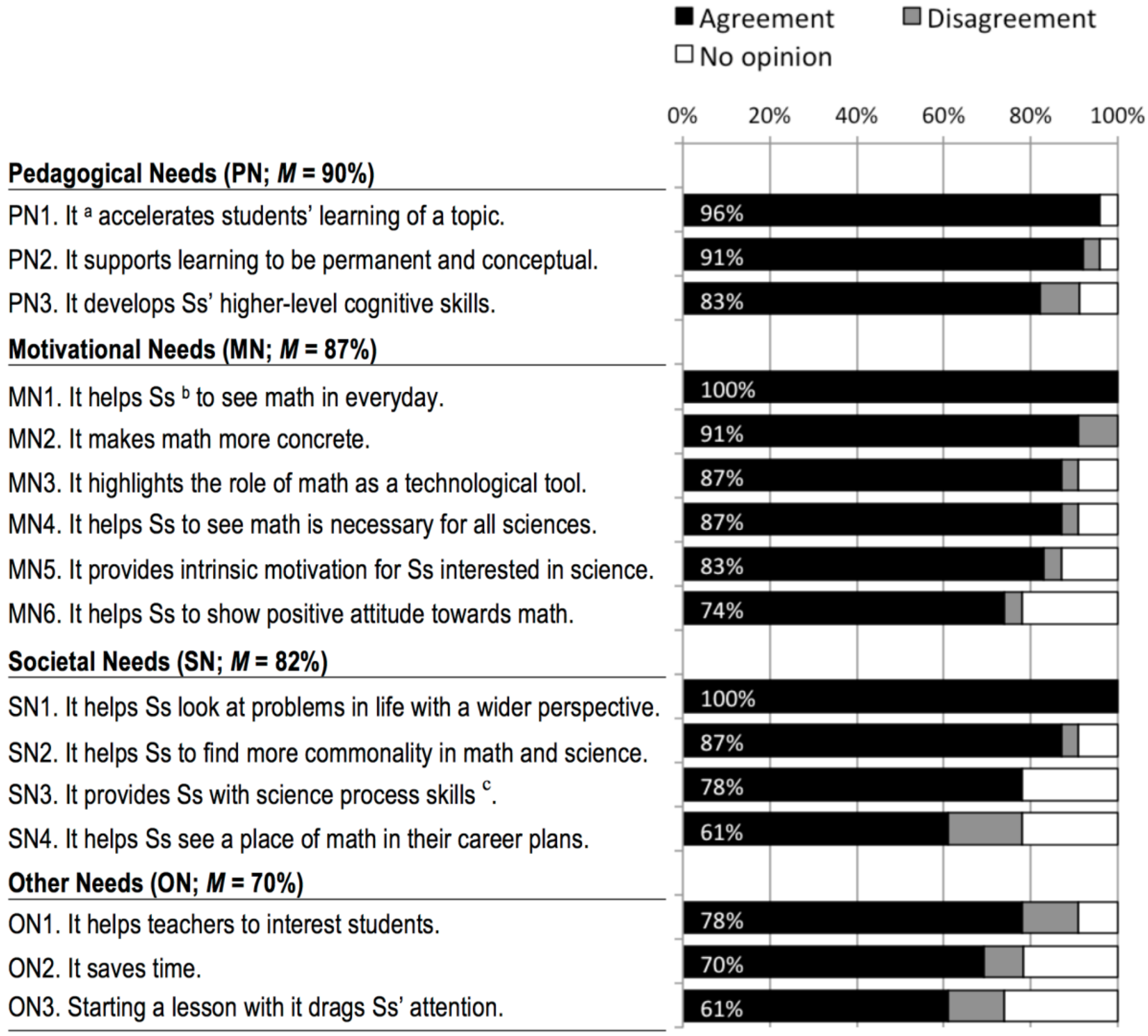

Figure 3. Experts' (*N* = 23) consensus of the needs for CIMAS; the items are renumbered in accordance with each consensus; Note. [a] the curriculum integration of mathematics and science, [b] students, [c] strategy development, independent thinking, use of scientific languages

revealed that the experts dissented from the disadvantages and thus expected robust positive influences on students' learning. Since all open-ended responses captured in the 1st-round survey were included to compile the 2nd-round survey, these dissented items were considered to present the experts' diverse opinions on CIMAS.

IMPLICATION

Experts' perceived needs of CIMAS

Compiling the experts' degree of consensus plus the reviewed literature, this section highlights directional explanations how CIMAS would enhance students' learning, in terms of pedagogical, motivational, societal, and other needs. The discussion presumes that highly consented items would more likely take place with a prior sequence than other lower-consented items. All items were ordered according to the degree of their consensus.

Pedagogical needs. The experts highly agreed that CIMAS would support and accelerate students' learning of a topic in mathematics (PN1, 96%). Their responses also indicate that the learning takes place in a more permanent and conceptual mental process by means of connections between multidiscipline knowledge (PN2, 91%). Through supporting students to compare various ideas and to construct connections from different views, the integration of science and mathematics would develop their higher-level cognitive skills such as analyzing, synthesizing, and interpreting numerical data (PN3, 83%). In this light, curriculum integration is claimed to support students to achieve in more complex problems (Klein, 2005) and, eventually, in both mathematics and science lessons (Cosentino, 2008). Such a meaningful learning would lead students to making connections and applying knowledge in different contexts, which is set as one of the educational objectives in Turkey (MoNE, 2011). Hence, the

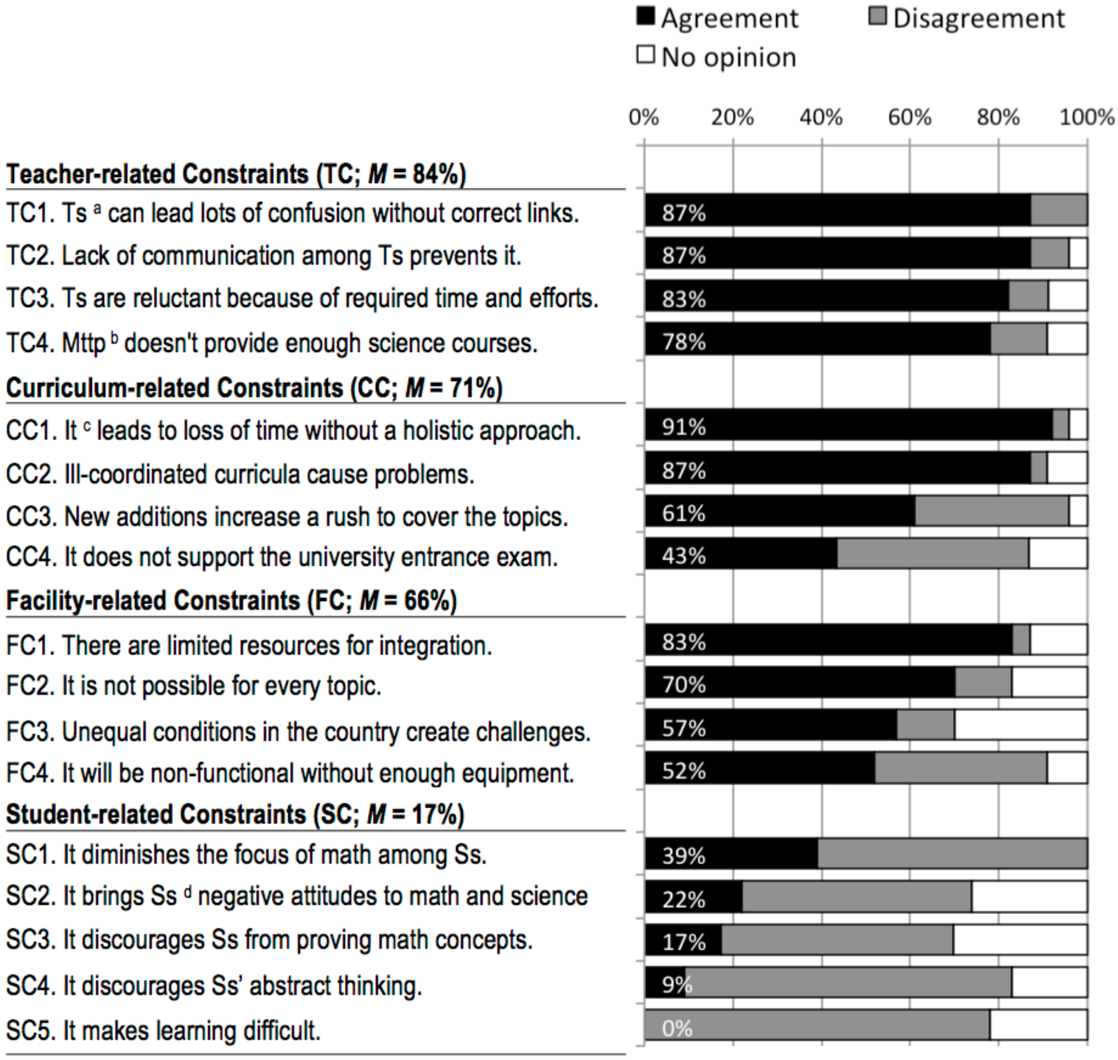

Figure 4. Experts' (N = 23) consensus on the constraints of CIMAS; the items are renumbered in accordance with each consensus; Note. [a] teachers the curriculum integration of mathematics and science, [b] mathematics teacher training programs, [c] the curriculum integration of mathematics and science, [d] students

curriculum integration has been claimed to be an effective approach that converts traditional instructions characterized by mere memorization and prescribed steps into the constructivist instruction (Kaya et al., 2006; Klein, 2005; Loepp, 1999). In summary, from the pedagogical needs, CIMAS would likely take place as the flow list indicates below:

CIMAS → increases connections and applications → develops cognitive understanding and makes learning long-lasting, conceptual, and meaningful → students' higher level of cognitive skills → higher achievement in mathematics

Motivational needs. All participant experts agreed that CIMAS would allow students to see the use of mathematics in everyday life (MN1, 100%). This complete consensus can be supported by the ideas that mathematics and science are complementary to each other and integration of them is highly feasible and relevant to real world applications (Frykholm & Glasson, 2005). The experts highly believed that the integration makes mathematics more concrete and provides students the ability to see mathematics as a necessary tool for science (MN2, 91%). Therefore, it can be inferred that science allows mathematics to be more concrete and related to everyday life. In another sense, curriculum integration would help students to find answers how mathematics plays its role in supporting technology and science development (MN3, 87%; MN4, 87%). Furthermore, students in Turkey were determined to believe that receiving information about reasons and importance of mathematics would be beneficial and motivational for their learning (Costu, Arslan, Çatlioglu, & Birgin, 2009).

These expert responses from MN1-4 lead to a consequential idea that the integration provides intrinsic motivation for students who are interested in science (MN5, 83%), and eventually develops their positive attitudes (MN6, 74%). Jacob (1989), Hoaclander (1999), Klein (2005), and Cosentino's (2008) claims are in line with the experts' consensus: integration of science and mathematics helps to increase real life examples; the mathematics curriculum should be taught through real life situations to increase students' motivation and positive attitudes toward mathematics. In summary, the motivational would take place as the flow list indicates below:

CIMAS → increases real life connections in mathematics → makes mathematics more concrete (e.g., usage in technological and scientific developments) → increases motivation & positive attitudes towards mathematics

Societal needs. All experts agreed that integration helps students to approach problems in real life with a wider perspective (SN1, 100%). Students are expected to understand the importance of multidisciplinary studies. They might have perceived science and mathematics as heterogeneous disciplines; however, CIMAS would help them to find the commonality (SN2, 87%). This capacity is beneficial in this information age, since society expects students as future citizens to solve contextual problems. The previous literature indicated that the growth of knowledge would require the integration of knowledge in mathematics education as a career requirement for this scientific era (Jacobs, 1989; Kaya et al., 2006). In the same light, the experts agreed that that integration of science and mathematics would improve students' science process skills such as strategy development, independent thinking, and use of scientific language (SN3, 78%). By means of the integration, more than half of participants agreed that, students would realize the use of mathematics in their career plans (SN4, 61%). Considering the curriculum objective that students are expected to realize widespread areas of using these science process skills in their real life and in career fields (MoNE, 2011), CIMAS would be a strategy for increasing mathematics-competent citizens. In summary, the societal needs can be presented as the flow list indicates below:

CIMAS → enables students' wider perspective about science and mathematics → highlights commonality between mathematics and science → improves science process skills → prepares human resources with higher mathematics competence

Other needs. The experts' responses about the supplementary needs are collected in this category with regards to teachers' effective instruction. CIMAS would help teachers to interest students (ON1, 78%) and to manage class time more effectively (ON2, 70%). McBride and Silverman's (1991) concern that time would be required more for instructing mathematics concepts through science was not applicable in this study. Rather, the experts expected a more effective instructional environment; CIMAS would help teachers attract students' attention (ON3, 61%). One possible explanation of the contrast could be found in Lonning and DeFranco's (1997) study. They claimed that, if plural topics are taught together, the integration creates more comprehensive meaning to students than taught separately. Eventually, the integration could help to save instructional time and to provide a more effective teaching environment. In summary, the other needs can be presented as the flow list indicates below:

CIMAS → increases student curiosity → saves time & drags students' attention easier → provides the effective environment for instruction

DISCUSSION

Dissented disadvantages and significant obstacles

Although some previous research indicates that integration might cause limited learning (Wicklein & Schell, 1995) and students might have difficulties to focus on main concepts in integrated lessons (Cosentino, 2008), the experts' responses in this study did not present significant agreement on these disadvantages (SC1, 39%). CIMAS was believed unlikely to cause negative attitudes toward mathematics (SC2, 22%), unlikely to prevent students' abstract thinking or ability to prove (SC3, 9%), or not to relate to learning difficulty (SC4, 0%). This notable dissensus indicate that the curriculum integration would not involve any disadvantage related to students' learning process.

With all the consistent consensus that CIMAS would enhance students learning through fulfilling the pedagogical, motivational, and societal needs, there still exist the significant obstacles of its implementation in schools. Success in the implementation of curriculum integration was robustly related to how much curriculum redesign is successful and innovative (Wicklein & Schell, 1995). A lesson taught through curriculum integration can demand more responsible collaboration, efforts, and time. As shown in the experts' responses, teachers without extended knowledge about science were expected to lead students to their learning confusion (TC1, 87%). As the experts responded, CIMAS might induce loss of time if it is planned without a holistic approach (CC1, 91%), while they contradictorily agreed that it saves time for learning process in the other needs. In current schools, there exists limited resource that can be used by teachers and students, since curriculum is not regulated for any multidisciplinary integration (FC1, 83%). According to Gokcek and Baki (2013), these are the general concerns among current Turkish mathematics teachers, which indicates that the concerns with CIMAS could be resolved on the continuum of curriculum reforms.

Teachers' background knowledge of commonalities between mathematics and science was recognized as a significant constraint both in the experts' responses and the previous literature. These obstacles, originated from lack of both communication and holistic approaches across different disciplines, should be considered in the planning process of curriculum integration. Although experienced teachers believed they had more background knowledge than preservice teachers, the large amount of experienced teachers still felt their knowledge was not enough (Lehman, 1994). Likewise, Berlin and White (2010) concerned that a preservice teacher program might fail to change their perceived difficulty of curriculum integration over the master's program. Therefore, there emerges a need to address the curriculum integration, specifically a multidisciplinary approach, for both inservice and preservice teacher-training programs (Balay, 2004; Loepp, 1999).

How to enlarge the scope of CIMAS: Collaboration

The 10 mathematics topics were responded to be the most appropriate for the curriculum integration of mathematics and science (CIMAS): derivative and integral, functions, equations, numbers, logarithms and exponential functions, graphs, ratio and proportion, statistics, and logic. These topics would be beneficial for mathematics teachers to enrich their lessons by integrating them with physics, chemistry, or biology. In line with this feasibility of CIMAS, the experts gave integration examples referring to all mathematics units of the high school mathematics curriculum in Turkey. Therefore, every mathematics unit could be integrated with at least one of the three branches of science in a form of student inquiry activities, problem solving, or introductory examples.

However, of note is that a majority of the experts still answered that the integration would not be applicable to each of mathematics topics (FC2, 70%). These two contradictory arguments could have originated from the fact that teachers or academics are not individually capable of promoting integration for each of the topics in mathematics, but are able to focus on certain discrete topics. Thus, to combine discrete ideas of the curriculum integration, an effective collaboration is required. This highlights the reason teachers in schools need to work cooperatively during a curriculum integration process for students' effective learning outcome (Wicklein & Schell, 1995). For example, extra collaborative efforts would be required to overcome the biased topics for CIMAS in physics. Among the integration examples, the physics topics were responded significantly more than those in chemistry or biology. Furthermore, other than the three combinations of the most commonly perceived integrations—derivative with linear velocity, ratio with chemical mixture, and probability with genetics—found in the 1st-round survey, more units should be designed and implemented in an experimental study to ensure if they fulfill the pedagogical, motivational, and societal needs. These trials collaborated by academics and schoolteachers across mathematics and science disciplines would enable them to enlarge the scope of CIMAS.

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Appendix 1. Summary of the procedure of data collection and analysis

Participants	Instrument
1st-round open-ended survey opened in December 2011	
The survey invitation was sent to - 44 academics in Ankara - 33 teachers in the two private schools.	- The *1st*-round survey contained 5 open-ended questions that address the research questions.
Responses from 1st-round in January 2012	
The responses were collected from - 7 academics - 16 teachers in the schools	- The responses for the appropriate topics were analyzed using frequency distribution and chi-square test. - The responses for the needs and constraints were categorized to constitute the Likert scale survey
2nd-round Likert scale survey opened in February 2012	
It was sent to - 7 academics - 16 teachers in the schools	- The 2nd-round survey contained 33 opinions asked by the scale (agree-disagree-no opinion) - The pedagogical, motivational, societal, and other needs were asked in 16 items. - The teacher-, curriculum-, facility-, and student-related constraints were asked in 17 items.
Responses from 2nd-round Likert-scale survey in March 2012	
The responses were collected from - 7 academics - 16 teachers in the schools	- By calculating mean, the degree of agreement on them was analyzed. - Category means were compared by calculating each average mean.