Eğitim ve Bilim
2014, Cilt 39, Sayı 171

Education and Science
2014, Vol. 39, No 171

Introducing STEM Education: Implications for Educating Our Teachers For the Age of Innovation

FeTeMM Eğitimi ve Alan Öğretmeni Eğitimine Yansımaları

M. Sencer Corlu[1] **Robert M. Capraro**[2] **Mary M. Capraro**[3]
Bilkent University **Texas A&M University**

Abstract

Reforms in education of Science, Technology, Engineering, and Mathematics (STEM) disciplines have been particularly critical for the economic competitiveness of Turkey. There has been some criticism of the reforms at the teacher education level, claiming that Turkish teachers were not prepared to address the needs of their profession. The authors of this article introduced the STEM education model, which was designed with a critical investigation of the previous research on curriculum integration, STEM education, teaching knowledge, and Turkish educational reforms. By focusing on the interaction of mathematics and science, the model emphasized the importance of integrated teaching knowledge to successfully transition from the departmentalized model of teaching to an integrated model that promotes innovation.

Keywords: STEM education, integrated teaching knowledge, mathematically rigorous science education

Öz

Fen, Teknoloji, Mühendislik ve Matematik (FeTeMM) ülkemizin uluslararası ölçekte rekabet gücünün korunabilmesi için stratejik öneme sahiptir. Bu alanlarda uzmanlaşacak insan gücünü yetiştirmesi beklenen öğretmenlerimizin çağın gereklerine uygun şekilde eğitilmedikleri konusunda yoğun eleştiriler vardır. Bu makale ile FeTeMM eğitiminin kuramsal bir çerçeve etrafında tanıtılması amaçlanmıştır. Bu amaca yönelik olarak bütünleşik müfredat ve öğretmenlik bilgisi alanlarında ülkemizde ve dünyada yapılmış araştırmalar ile süregelen eğitim reform girişimleri incelenmiştir. Kavramlaştırılan modelin bir çıktısı olan fen ve matematik arasındaki etkileşime yoğunlaşıldığında, öğretmenlerimizin sadece uzman oldukları alanda öğretmenlik bilgisine sahip olmalarının ülkemizin ihtiyacı olan insan gücünü yetiştirmede yeterli olmayacağı sonucuna varılmıştır.

Anahtar Sözcükler: FeTeMM eğitimi, bütünleşik öğretmenlik bilgisi, matematiksel fen eğitimi

[1] Assistant Professor, Bilkent University, Graduate School of Education, sencer.corlu@bilkent.edu.tr
[2] Professor, Texas A&M University, Dept. of Teaching, Learning and Culture, rcapraro@tamu.edu
[3]Associate Professor, Texas A&M University, Dept. of Teaching, Learning and Culture, mmcapraro@tamu.edu

Introduction

Nations invest in innovation to promote sustainable economic growth. While many countries are suffering from the effects of global economic difficulties, such as rising unemployment and soaring public debt, the role of labor input is decreasing in the 21st century economy. Only innovation-driven growth has the potential to create value-added jobs and industries (Organisation for Economic Co-operation and Development [OECD], 2010a). Because innovation is largely derived from advances in the science, technology, engineering, and mathematics (STEM) disciplines (National Academy of Sciences, National Academy of Engineering, & Institute of Medicine, 2011), an increasing number of jobs at all levels require STEM knowledge (Lacey & Wright, 2009). Nations need an innovative STEM workforce to be competitive in the 21st century.

Innovation involves the integration of diverse STEM skills and transcends disciplines. Innovation is a highly interactive and multidisciplinary process/product that rarely occurs in isolation and is tightly connected to life (OECD, 2010a). Today, there is a clear consensus among stakeholders on the importance of STEM education to economic innovation (Kuenzi, 2008; OECD, 2010b). STEM education in K-12 settings fosters interdisciplinary knowledge and skills that are relevant to life and prepare students for a knowledge-based economy (National Research Council, 2011). The overarching goal of STEM education is to raise the current generation with innovative mindsets.

STEM education includes the knowledge, skills and beliefs that are collaboratively constructed at the intersection of more than one STEM subject area. The purpose of the present paper is to introduce STEM education in the Turkish context, which is conceptualized through a critical investigation of the global and local educational policies, previous research on curriculum integration and integrated teaching knowledge (ITK), and the Turkish educational reforms.

Theoretical Framework of STEM Education

Curriculum integration provides the theoretical framework for STEM education. Integrative learning and curriculum integration theories reflect the progressive tradition of Dewey, in which subject matter is connected to real-life and made more meaningful to students through curriculum integration (Beane, 1997). John Dewey's elegant statement, "Relate the school to life, and all studies are of necessity correlated" (Dewey, 1910, p. 32) serves as an inspiration to educators who intuitively believe that curriculum integration produces greater learning outcomes in school subjects despite the lack of empirical evidence (Czerniak, Weber, Sandman, & Ahern, 1999; Frykholm & Glasson, 2005; McBride & Silverman, 1991). A major obstacle to conducting empirical research on curriculum integration is the different definitions of curriculum integration among scholars (Berlin & White, 1994, 1995). In this regard, some propose curriculum integration models that are too general and lack rigor in domain-specific knowledge while other models of curriculum integration posit radical changes in the K-12 school curriculum through interdisciplinary approaches (Hartzler, 2000). "The rigidity and resilience of the school curriculum structure should not be underestimated when proposing reform" (Williams, 2011, p. 27), likewise, many researchers ignore the power of status quo practices and teachers' lack of readiness to adopt integrated approaches in their teaching (Schleigh, Bossé, & Lee, 2011). Nevertheless, curriculum integration helps educators understand four STEM disciplines as an interconnected entity with a strong connection to life.

STEM education builds upon curriculum integration theories in two perspectives. One perspective is that STEM education enables teachers to integrate correlated subjects without ignoring the unique characteristics, depth, and rigor of their main discipline (National Research Council, 2011). However, there is a gap between how STEM subjects are taught in schools and the knowledge, skills, and beliefs required for STEM education (Cuadra & Moreno, 2005). Reducing the gap between current instructional practices and the actual skills needed for STEM education is contingent upon the expertise of STEM teachers to successfully transition from the departmentalized model of teaching to an integrated teaching model (Furner & Kumar, 2007). In this model, teachers are not only the expert of a single subject, but also have the additional responsibility of guiding their students in at least one other STEM subject (Sanders, 2009), which necessitates an investment in professional development of in-service teachers, as well as reorganizing the teacher education programs at universities (Kline, 2005). The second perspective is in regard to the STEM education curriculum that guides the teachers. A highly structured curriculum with rigid boundaries among STEM disciplines is likely to weaken the effectiveness of the teachers (Pinar, Reynolds, Slattery, & Taubman, 2000) whereas a flexible curriculum enables teachers to teach STEM subjects in their natural contexts in contrast to disparate curricular disciplines (Jardine, 2006). STEM education requires teachers to excel in utilizing natural and active exchanges of knowledge, skills, and beliefs among STEM disciplines.

STEM Education Model

The model in Figure 1 delineates the focus of teaching in STEM education. The model links the (*integrated) STEM education* to *integrated teaching* at the K-12 level. While the oval STEM shapes indicate the preservation of unique characteristics within each STEM discipline, such as in-depth knowledge, skills, and beliefs, the arrows from the shapes represent the teacher and student-driven interactions. The interactions exist because they are often integral parts of the STEM disciplines, rather than optional. However, the model also hypothesizes that it takes a well-educated teacher with a strong ITK to such interactions actually occur in the classroom settings. The notion of ITK is defined at the nexus of STEM teacher's expert content and pedagogical content knowledge in their main subject area and working knowledge in another STEM subject, which is mainly developed through participation in professional learning communities (Corlu, 2014). The model is designed with the potential to address all other interactions between STEM subjects; however, the conceptualization of ITK is beyond the scope of the current paper.

The proposition that posits *mathematics is abstract but science is concrete* is not supported in practice. In contrast to one view, which argues that mathematics and science are epistemologically too different to be integrated (Williams, 2011), authors of the current paper believe that both subjects are related to life and dependent on each other to construct new knowledge (Akman, 2002; Başkan, Alev, & Karal, 2010; Levin, 1992; Ogilve & Monagan, 2007; Pratt, 1985). From this perspective, the relationship of mathematics and science can be defined according to different perspectives that emphasize one over the other, such as *mathematics used in science* or *mathematically rigorous science education*, depending on the expert knowledge of the teacher. In this regard, post-modern perspective claim that mathematics and science are indispensible to each other, being supported by an pluralistic understanding of the concrete applications and abstract functionalities that people gave to them (cf. Skovsmose, 2010). This post-modern view helps educators understand STEM education as an integrated entity. Therefore, STEM education invalidates the clear-cut distinction of mathematics and science.

STEM education at the K-12 level can occur at the intersection of mathematical and scientific content and processes, such as problem solving and quantitative reasoning (Basista & Mathews, 2002; Frykholm & Meyer, 2002; Pang & Good, 2000). Students at the K-12 level experience mathematics extensively across the mathematically rigorous science curriculum (Jones, 1994). For example, while science teachers use mathematics as a tool or an inscription device (Roth, 1993; Roth & Bowen, 1994). mathematics teachers use science as an application (Davison, Miller, & Metheny, 1995). Mathematics used in science or mathematically rigorous science education provide educators with an understanding of STEM education that does not create an independent meta-discipline while preserving the subject-specific knowledge, skills, and attitudes.

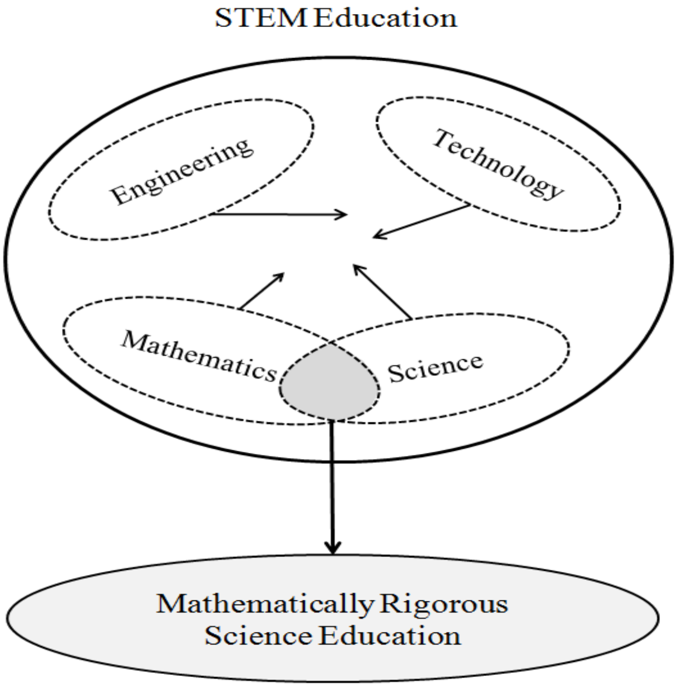

Figure 1. STEM education model with a particular focus on mathematics and science.

The Impetus for STEM Education in Turkey

Many countries around the world, including global economic powers such as the United States and the European Union (EU) are transforming their educational systems to be competitive in the age of innovation (Fensham, 2008). STEM education is at the core of both American (Department of Education, 2010; National Economic Council, Council of Economic Advisers, & Office of Science and Technology Policy, 2011; National Science Board, 2010; President's Council of Advisors on Science and Technology, 2010) and EU (Commission of the European Communities, 2008, 2010) research-based innovation strategies. Innovation strategies provide a vision for policymakers and a motivation for public and private STEM initiatives to raise interest in STEM and STEM teaching (e.g., Partnership for 21st century skills, STEM education coalition and UTeach in the United States and Scientix, InGenious and European Schoolnet in the EU). The immediate goal of STEM initiatives is to increase the number and quality of STEM teachers so that well-educated teachers can help more students develop 21st century skills and a capacity to innovate. In many countries, educational reforms focus on increasing interest in STEM and STEM teaching.

Turkey, a founding member of OECD, is going through major reforms to meet standards (*acquis*) as a candidate country for EU membership. Reforms in education of STEM disciplines are particularly critical for the economic competitiveness of Turkey because the innovation productivity of human capital in Turkey falls behind other developed countries (Turkish Academy of Sciences, 2010). Despite significant improvements in the last decade, the number of research development workforce per population is still among the lowest of OECD countries (OECD, 2010a). In response to the unsatisfactory innovation performance of the country, the administration is enacting regulations similar to American and European innovation strategies and educational policies (Grossman, Onkol, & Sands, 2007; Lonnqvist, Horn, & Berktay, 2006). In fact, *Vision 2023 project* (Serbest, 2005) and *2010-2014 Strategic Plans* (MoNE, 2009d, 2009e) are foresight exercises with an implicit agenda to improve quality of and access to STEM education (Uzun, 2006). Although there is a clear consensus on the necessity of educational reforms, several stakeholders have criticized current reforms for not considering the political, social, and technological history of the country (Tuzcu, 2006). Criticisms have also been leveled at the rapid introduction of reforms at the macro level with minimal consideration to the difficulties at the micro level (Yağcı, 2010). Turkish educational reforms are in accordance with EU and OECD innovation strategies but reforms also need to recognize the specific challenges and working practices in the country (Scientific and Technological Research Council of Turkey, 2010).

STEM Education at Turkish Schools

The Ministry of National Education (MoNE) in Turkey manages one of the largest educational systems in Europe with the continent's most centralized and selective system (Fretwell & Wheeler, 2001). MoNE not only regulates the teacher employment and relocation, but also imposes the curriculum, timetables, textbooks used in the classroom, and explicitly uses tests to have power over the teaching practices in the classroom. The non-political rationale that supports the current centralized and selective system is the massive size of the youthful citizenry in the country (Baki & Gokcek, 2005). Indeed, out of the 75 million people in the country, more than 16 million are students at the formal primary (5.5 million students in grades 1 to 4), lower secondary (5.5 million students in grades 5 to 8) or upper secondary (5 million students in grades 9 to 12) education levels, who are educated by over 800,000 active teachers on duty (MoNE, 2012). In order to allocate the limited resources to the large student population on merit—rather than equality—the educational system relies on the success of centrally administered standardized and multiple-choice tests. Tests select the ablest out of masses for an education at elite upper secondary and higher education institutions (Turkish Education Association, 2008, 2010). The student selection process begins in grade 6 (MoNE, 2013) and starts to channel the ablest to specialized education at the upper secondary level. The complexity of the selection process does not change the fact that the system works to provide a limited number of selected students, who encompass approximately 6% of the entire student body, with the best available education in specialized upper secondary schools (e.g., elite Anatolian schools, science schools, social science schools, police and military academies, etc.) (cf. Özel, Yetkiner, Capraro, & Küpçü, 2009). The centralized and elitist system of MoNE results in an early labeling of the large student body in terms of their performances on tests (Republican People's Party, 2011; Turkish Education Association, 2010).

Only a small percentage of Turkish students, who are educated in specialized schools, meet the international standards in STEM disciplines. School type is a major predictive factor of Turkish students' success in STEM subjects (Alacaci & Erbaş, 2010). Students from specialized schools perform consistently well at International Mathematical and Physics Olympiads, placing Turkey within the top 10 countries (Gorzkowski & Tichy-Racs, 2010; Webb, 2011). However, randomly selected Turkish students rank below the sixtieth percentile in international comparison studies in mathematics and science (Provasnik, Gonzales, & Miller, 2009). When the performance of specialized and general public schools is analyzed separately, the results vary significantly in favor of specialized schools with up to two standard deviation difference in mathematics and science performance (Berberoğlu, 2007). Based on such findings, some claimed that the majority of the students in Turkey are not receiving a quality education in STEM subjects (Sarıer, 2010).

The implementation of education in STEM disciplines in Turkey varies according to the school level, school type, and teacher characteristics, respective to each school level and type. The first discrepancy in education of STEM subjects occurs at the school level with increasing departmentalization after grade 5. Although MoNE's intended curriculum encourages lower secondary school teachers of mathematics and science to collaborate and integrate their coursework (MoNE, 2005, 2006, 2009a, 2009b; 2013), the enacted curriculum is particularly departmentalized and focuses on standardized tests (Özden, 2007). At the upper secondary school level, departmentalization in STEM subjects increases as mathematics and science courses are organized as standard and high level courses with less content at the standard level, creating an inequity in access to certain topics of mathematics and science. The second discrepancy in education of STEM subjects is based on school type as some specialized schools offer more advanced mathematics and science courses and a greater number of instructional hours in these subjects (MoNE, 2010a). The third discrepancy is the age and experience of teachers at different school levels and types. The majority of the STEM teachers at the lower secondary school level are below the age of 30 and on average have less than five years of teaching experience (MoNE, 2009c). In contrast, the majority of the STEM teachers in upper secondary schools have more than 15 years of teaching experience and are above the age of 30 (MoNE, 2010b). Furthermore, for specialized schools, MoNE recruits only teachers with substantial experience and who perform well at a content-based standardized selection test (Gür & Çelik, 2009; Özoğlu, 2010). The implementation of education in STEM disciplines in Turkey depends on school level and type, as well as the characteristics of STEM teachers.

STEM Teacher Education in Turkey

Three major institutional organizations are involved in the STEM teacher education system in Turkey: Universities, Council of Higher Education (CoHE), and MoNE. Traditionally, universities educate prospective STEM teachers in the faculties of education; however, the system that enables universities to educate prospective STEM teachers in upper secondary schools teacher education departments is recently abandoned. The future of these departments and the field of subject teacher education in Turkey is at stake. While CoHE holds the responsibility of organizing the curriculum for the teacher education programs, MoNE's operational duty is to select the new teachers to employ at public schools.

Each institution has its own interests and concerns. First, the actual recruitment capacity (in terms of budget and need) of MoNE is limited. As a result, over 350,000 young men and women, mostly graduates of faculty of sciences, are actively seeking employment (Özoğlu, 2010). Despite this, the universities continue to organize for-profit quick-fix teacher certification programs for the graduates of faculty of science. In addition, many other programs at universities are struggling to be accredited at European Union standards for instructional quality, research, and academic freedom (Turkish Academy of Sciences, 2010). Second, CoHE changes the standard teacher education curriculum frequently with little research support and without consulting the subject teacher educators at universities (Aslan, 2003). In particular, teacher educators criticize the STEM teacher education curriculum for ignoring the teaching practice and pedagogical content knowledge in the program (Çorlu & Corlu, 2010). Third, Public Personnel Selection Examination (PPSE) is the only criterion that MoNE considers for teacher employment. The PPSE emphasizes general pedagogy knowledge over the pedagogical content knowledge (see CoHE, 2007). Subject teacher educators believe that the current teacher employment system is damaging the credibility of teacher education programs at the universities because teacher candidates prefer studying for the PPSE rather than actually learning to teach. Further, MoNE recruits experienced teachers to teach at specialized schools based on their scores on a content-based examination with no reference to pedagogical content knowledge (Özoğlu, 2010). Given the OECD's Teaching and Learning International Survey (TALIS) finding that the need for well-educated teachers in Turkey is twice the international average (Büyüköztürk, Akbaba Altun, & Yıldırım, 2010; OECD, 2009a), it is evident that the teacher education system of Turkey is not functioning well (Kartal, 2011). The problems within the universities, CoHE, and MoNE, in addition to the lack of coordination among them (Gür & Çelik, 2009) are limiting the success of STEM education in the country.

Conclusion

The Importance of Integrated Teacher Education Programs

In an increasingly knowledge-based economy, nations need well-educated STEM teachers who can raise the current generation with a capacity to innovate. Integrated teacher education programs prepare future teachers equipped with the knowledge, skills, and beliefs to effectively implement STEM education that increases the innovation capacities of students (Cuadra & Moreno, 2005). Pre-service teachers, who graduate from integrated teacher education programs with the integrated teaching knowledge, understand and teach STEM as an interconnected entity with a strong collaborative connection to life. They graduate with the ability to positively affect their students' achievement, beliefs, and attitudes (Tschannen-Moran & McMaster, 2009), and lead more and better prepared students to stay in the STEM pipeline (Burkam & Lee, 2003; Subotnik, Tai, Rickoff, & Almarode, 2010). Integrated teacher education programs educate future teachers to implement STEM education so that they can increase students' innovation capacities (National Research Council, 2011).

STEM teachers in Turkey need to be prepared to adopt the changes introduced by curriculum reforms at the K-12 level. Integrated teacher education programs may prepare pre-service teachers with the necessary skills to implement reforms. In an integrated program, pre-service teachers experience the complexity and challenges of curriculum integration (Berlin & White, 2010; Offer & Mireles, 2009). Pre-service mathematics and science teachers develop an understanding and appreciation of the nature and teaching of the other subject area by monitoring their peers during micro teaching sessions while they learn to collaborate during integrated teaching courses (Capraro, Capraro, Parker, Kulm, & Raulerson, 2005; Çorlu & Corlu, 2012). In an integrated teacher education program, pre-service teachers are educated to become the driving force and genuine supporters of the reforms that aim to transition from the departmentalized model of STEM teaching and learning to an integrated model that promotes innovation (Furner & Kumar, 2007).

Policy Implications

Policy coordination between K-12 and higher education will increase the quality of pre-service teacher education outcomes. This policy coordination can be realized from two perspectives: teacher education programs and a teacher employment system. Teacher education programs developed in tandem with K-12 school curriculum will help pre-service teachers experience teaching environments that resemble K-12 school settings. It can be expected that pre-service mathematics and science teachers, who are educated with an awareness of the realities of K-12 school teaching, will become more self-confident and mentally prepared to implement STEM education (Berlin & White, 2010; Darling-Hammond, 2006). Second, a teacher employment system, collaboratively designed by policy makers at K-12 and higher education levels and based on performance in pre-service teacher education will provide a better assessment of pre-service teachers' readiness to implement STEM education. This will help restore the credibility of mathematics and science teacher education programs. Respectively, pre-service mathematics and science teachers, who believe in the relevance of their education, need not seek alternative methods to learn and practice teaching. Policy-making organizations at K-12 and higher education levels need to develop policies and enact reforms in a coordinated manner (Gür & Çelik, 2009) to positively affect the professional development, recruitment, and retention of teachers (Öztürk, 2005).

Teacher education programs should provide pre-service mathematics and science teachers with more opportunities to practice for the profession. A program that emphasizes teaching practice through integrated teaching knowledge may better prepare pre-service mathematics and science teachers for the profession. Excessive emphasis on theory in the coursework through subject-area or pedagogy courses widens the gap between the realities of the K-12 level teaching and teacher education at the higher education level. Teacher education programs should graduate teachers who are experts in content and pedagogy rather than graduating content or pedagogy experts who are eligible to become teachers.

References

Akman, B. (2002). Mathematics in preschool. *Hacettepe University Journal of Education, 23,* 244-248.

Alacaci, C., & Erbaş, A. K. (2010). Unpacking the inequality among Turkish schools: Findings from PISA 2009. *International Journal of Educational Development, 30*(2), 182-192.

Aslan, A. K. (2003). Eğitim fakültelerinin yeniden yapılandırılmalarına ilişkin bir değerlendirme [An evaluation of the reform in faculties of education]. *Journal of Social Sciences Institute, 6*(9), 23-38.

Baki, A., & Gökçek, T. (2005). Comparison of the development of elementary mathematics curriculum studies in Turkey and the U.S.A. *Educational Sciences: Theory & Practice, 5*(2), 579-588.

Basista, B., & Mathews, S. (2002). Integrated science and mathematics professional development programs. *School Science and Mathematics, 102*, 359-370.

Başkan, Z., Alev, N., & Karal, I. S. (2010). Physics and mathematics teachers' ideas about topics that could be related or integrated. *Procedia Social and Behavioural Sciences*, *2*, 1558-1562.

Beane, J. A. (1997). *Curriculum integration: Designing the core of democratic education*. New York, NY: Teachers College Press.

Berberoğlu, G. (2007). *Türk bakış açısından PISA araştırma sonuçları* [The results of PISA survey from Turkish perspective]. Retrieved from http://www.konrad.org.tr/Egitimturk/07girayberberoglu.pdf

Berlin, D. F., & White, A. L. (2010). Preservice mathematics and science teachers in an integrated teacher preparation program for grades 7-12: A 3-year study of attitudes and perceptions related to integration. *International Journal of Science and Mathematics Education, 8*(1), 97-115.

Burkam, D. T., & Lee, V. E. (2003). *Mathematics, foreign language, and science course taking and the NELS: 88 transcript data* (NCES 2003-01). Washington, DC: U.S. Department of Education, National Center for Education Statistics.

Büyüköztürk, S., Akbaba-Altun, S., & Yıldırım, K. (2010). *TALIS Türkiye ulusal raporu* [TALIS Turkish national report]. Ankara: Milli Eğitim Bakanlığı Dış İlişkiler Genel Müdürlüğü.

Capraro, R. M., Capraro, M. M., Parker, D., Kulm, G., & Raulerson, T. (2005). The mathematics content knowledge role in developing preservice teachers' pedagogical content knowledge. *Journal of Research in Childhood Education, 20*(2), 102-118.

Commission of the European Communities. (2008). *Report of the commission of the European communities on progress towards the Lisbon objectives in education and training*. Retrieved from http://ec.europa.eu/education/lifelong-learning-policy/doc/report08/report_en.pdf

Commission of the European Communities. (2010). *Report of the commission of the European communities on Lisbon strategy evaluation*. Retrieved from http://ec.europa.eu/archives/growthandjobs_2009/pdf/lisbon_strategy_evaluation_en.pdf

Corlu, M. S. (2014). FeTeMM eğitimi araştırmaları: Alanda merak edilenler, fırsatlar ve beklentiler [STEM education research: Latest trends, opportunities, and expectations]. *Turkish Journal of Educational Research*, *3*(1), 4-10.

Çorlu, M. A., & Corlu, M. S. (2010, May). *The future of undergraduate science-mathematics teaching programs*. Paper presented at the International Symposium of Teacher Education Policies and Problems, Ankara, Turkey.

Çorlu, M. A., & Corlu, M. S. (2012). Professional development models through scientific inquiry in teacher education. *Educational Sciences: Theory & Practice, 11*(1), 5-20.

Council of Higher Education. (2007). *Öğretmen yetiştirme ve eğitim fakülteleri: 1982 - 2007* [Teacher education and the faculties of education: 1982 - 2007]. Ankara, Turkey: Author.

Cuadra, E., & Moreno, J. M. (2005). *Expanding opportunities and building competencies for young people: A new agenda for secondary education*. Washington, DC: The World Bank.

Czerniak, C. M., Weber, W. B., Sandman, A., & Ahern, J. (1999). A literature review of science and mathematics integration. *School Science and Mathematics, 99*, 421-430.

Darling-Hammond, L. (2006). Assessing teacher education: The usefulness of multiple measures for assessing program outcomes. *Journal of Teacher Education*, *57*(2), 120-138.

Davison, D. M., Miller, K. W., & Metheny, D. L. (1995). What does integration of science and mathematics really mean? *School Science and Mathematics, 95*, 226–230.

Department of Education. (2010). *ESEA blueprint for reform: The reauthorization of the elementary and secondary education act.* Washington, DC: Author. Retrieved from http://www2.ed.gov/policy/elsec/leg/blueprint/blueprint.pdf

Dewey, J. (1910). *How we think*. Boston, MA: Heath.

Fensham, P. J. (2008). *Science education policy-making: Eleven emerging issues* (ED-2007/WS/51 – CLD 2855.7). Paris: UNESCO.

Fretwell, D. H., & Wheeler, A. (2001). *Turkey: Secondary education and training.* (Secondary Education Series). Washington, DC: The World Bank.

Frykholm, J. A., & Glasson, G. E. (2005). Connecting mathematics and science instruction: Pedagogical content knowledge for teachers. *School Science and Mathematics, 105*, 127-141.

Frykholm, J. A., & Meyer, M. (2002). Integrated instruction: Is it science? Is it mathematics? *Mathematics Teaching in the Middle School,* 7(9), 502-507.

Furner, J. M., & Kumar, D. D. (2007). The mathematics and science integration argument: A stand for teacher education. *Eurasia Journal of Mathematics, Science & Technology Education, 3*(3), 185-189.

Gorzkowski, W., & Tichy-Racs, A. (2010). *List of winners in 1st-41st international physics olympiads*. Retrieved from http://dokutar.omikk.bme.hu/web/Konyvtar/IPHO.pdf

Grossman, G. M., Onkol, P. E., & Sands, M. (2007). Curriculum reform in Turkish teacher education: Attitudes of teacher educators towards change in an EU candidate nation. *International Journal of Educational Development, 27*(2), 138-150.

Gür, B. S., & Çelik, Z. (2009). *Türkiye'de millî eğitim sistemi: Yapısal sorunlar ve öneriler* [National education in Turkey: Structural problems and recommendations]. Ankara, Turkey: Siyaset, Ekonomi ve Toplum Araştırmaları Vakfı.

Hartzler, D. (2000). *A meta-analysis of studies conducted on integrated curriculum programs and their effects on student achievement* (Doctoral dissertation). Retrieved from ProQuest Dissertations and Theses (UMI No: 9967119).

Jardine, D. W. (2006). On the integrity of things: Reflections on the integrated curriculum. In D. W. Jardine, S. Friesen & P. Clifford (Eds.), *Curriculum in abundance* (pp. 171-179). Mahwah, NJ: Erlbaum.

Jones, K. (1994). Mathematics teaching from a different point of view. *Mathematics Education Review, 5*, 10-17.

Kartal, M. (2011). The experiences of Turkey in branch teacher training and sustainable new model approaches. *Buca Eğitim Fakültesi Dergisi, 29*, 50-57.

Kline, J. T. (2005). Integrative learning and interdisciplinary studies. *PeerReview, 7*(4), 8-10.

Kuenzi, J. J. (2008). *Science, technology, engineering, and mathematics (STEM) education: Background, federal policy, and legislative action* (CRS report for Congress). Retrieved from http://www.fas.org/sgp/crs/misc/RL33434.pdf

Lacey, T. A., & Wright, B. (2009). Occupational employment projections to 2018. *Monthly Labor Review,132*(11), 82-123.

Levin, S. A. (Ed.) (1992). *Mathematics and biology: The interface, challenges and opportunities*. Retrieved from http://www.bio.vu.nl/nvtb/Contents.html

Lonnqvist, A., Horn, R., & Berktay, N. (2006). Introduction. In P. Sahlberg (Ed.) *Proceedings of the international conference on curriculum reform and implementation in the 21st century: Policies, perspectives and implementation* (pp. 5-7). Ankara, Turkey: Ministry of National Education. Retrieved from http://www.pasisahlberg.com/

McBride, J., & Silverman, F.L. (1991). Integrating elementary/middle school science and mathematics. *School Science and Mathematics, 91*, 285-292.

Ministry of National Education. (2005). *İlköğretim fen ve teknoloji dersi 4. ve 5. sınıflar öğretim programı* [Primary schools science and technology education program for grades 4 and 5]. Ankara, Turkey: Author.

Ministry of National Education. (2006). *İlköğretim fen ve teknoloji dersi 6, 7 ve 8. sınıflar öğretim programı* [Primary schools science and technology education program for grades 6, 7, and 8]. Ankara, Turkey: Author.

Ministry of National Education. (2009a). *İlköğretim matematik dersi 1-5. sınıflar öğretim programı* [Primary schools mathematics education program for grades 1-5]. Ankara, Turkey: Author.

Ministry of National Education. (2009b). *İlköğretim matematik dersi 6-8. sınıflar öğretim programı ve kilavuzu* [Primary schools mathematics education program and guide for grades 6-8]. Ankara, Turkey: Author.

Ministry of National Education. (2009c). *İlköğretim OBBS raporu 2008* [Primary schools OBBS report]. Ankara, Turkey: Author.

Ministry of National Education. (2009d). *MEB 2010-2014 stratejik planı* [MoNE 2010-2014 strategic plan]. Ankara, Turkey: Milli Eğitim Bakanlığı Strateji Geliştirme Başkanlığı.

Ministry of National Education. (2009e). Öğretmen yetiştirme ve eğitimi genel müdürlüğü *2010-2014 stratejik planı* [Teacher training and education general directorate 2010-2014 strategic plan]. Ankara, Turkey: Author. Retrieved from http://oyegm.meb.gov.tr/stratejik_plan/stratejik_plan.htm

Ministry of National Education. (2010a). *Ortaöğretim kurumları haftalık ders çizelgeleri* [Secondary schools weekly timetables]. Ankara, Turkey: Author. Retrieved from http://ttkb.meb.gov.tr/prgcizelge.aspx

Ministry of National Education. (2010b). *Ortaöğretim OBBS raporu 2009* [Secondary schools OBBS report]. Ankara, Turkey: Basak Matbaacilik.

Ministry of National Education. (2012). *National education statistics: Formal education 2012-2013*. Ankara, Turkey: Author. Retrieved from http://sgb.meb.gov.tr/istatistik/meb_istatistikleri_orgun_egitim_2010_2011.pdf

Ministry of National Education. (2013). Ortak sinav: Tum sorular ve cevaplari [The common examination: All questions and answers]. Ankara, Turkey: Author. Retrieved from http://:/oges.meb.gov.tr/docs2104/ortak_s%C4%B1nav_t%C3%BCm_sorular_ve_cevaplar%C4%B1.pdf

National Academy of Sciences, National Academy of Engineering, & Institute of Medicine. (2011). *Rising above the gathering storm revisited: Rapidly approaching category 5: Condensed version.* Washington, DC: The National Academies Press.

National Economic Council, Council of Economic Advisers, & Office of Science and Technology Policy. (2011). *A strategy for American innovation: Securing our economic growth and prosperity*. Retrieved from http://www.whitehouse.gov/sites/default/files/uploads/InnovationStrategy.pdf

National Research Council. (2011). *Successful K-12 STEM education: Identifying effective approaches in science, technology, engineering, and mathematics*. Washington, DC: National Academy Press.

National Science Board. (2010). *Preparing the next generation of STEM innovators: Identifying and developing our nation's human capital*. Arlington, VA: The National Science Foundation.

Offer, J., & Mireles, S. V. (2009). Mix it up: Teachers' beliefs on mixing mathematics and science. *School Science and Mathematics, 109*, 146–152.

Ogilve, J. F., & Monagan, M. B. (2007). Teaching mathematics to chemistry students with symbolic computation. *Journal of Chemistry Education*, *84*, 889-896.

Organisation for Economic Co-operation and Development. (2009a). *Creating effective teaching and learning environments: First results from TALIS*. Retrieved from www.oecd.org/dataoecd/17/51/43023606.pdf

Organisation for Economic Co-operation and Development. (2010a). *Measuring innovation: A new perspective - online version.* Retrieved from http://www.oecd.org/document/22/0,3746,en_41462537_41454856_44979734_1_1_1_1,00.html

Organisation for Economic Co-operation and Development. (2010b). *The OECD innovation strategy: Getting head start on tomorrow. Retrieved from* http://www.oecd.org/dataoecd/3/14/45302349.pdf

Özden, M. (2007). Problems with science and technology education in Turkey. *Eurasia Journal of Mathematics, Science & Technology Education, 3*(2), 157-161.

Özel, S., Yetkiner, E. Z., Capraro, R. M., & Küpçü, A. R. (2009). Young adolescent education in Turkey. In S. B. Mertens, V. A. Anfara, & K. Roney (Eds.), *An international look at educating young adolescents* (pp. 1-23). Charlotte, NC: Information Age.

Özoğlu, M. (2010). *Türkiye'de öğretmen yetiştirme sisteminin sorunları* [The problems of teacher education system in Turkey]. Retrieved from http://www.setav.org/ups/dosya/20275.pdf

Öztürk, C. (2005). *Türkiye'de Dünden Bugüne Öğretmen Yetiştiren Kurumlar* [From the past to the present: Institutions that grow teachers in Turkey] (Rev. ed.). Istanbul: Marmara Üniversitesi Atatürk Eğitim Fakültesi Yayınları.

Pang, J., & Good, R. (2000). A review of the integration of science and mathematics: Implications for further research. *School Science and Mathematics*, *100*, 73-82.

Pinar, W. F., Reynolds, W. M., Slattery, P., & Taubman, P. M. (2000). *Understanding curriculum: An introduction to the study of historical and contemporary curriculum discourses*. New York, NY: Peter Lang Publishing.

Pratt, D. L. (1985). Mathematics usage in secondary science courses and textbooks. *School Science and Mathematics, 85*, 394-406.

President's Council of Advisors on Science and Technology. (2010). *Prepare and inspire: K-12 education in science, technology, engineering, and math (STEM) for America's future*. Retrieved from http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-stemed-report.pdf

Provasnik, S., Gonzales, P., & Miller, D. (2009). *U.S. performance across international assessments of student achievement: Special supplement to the condition of education 2009*. Washington, DC: U.S. Department of Education.

Republican People's Party. (2011). *Eğitim:Eşit fırsat yaşam boyu öğrenme* [Education: Equal opportunity for life long learning]. Retrieved from http://www.chp.org.tr/wp-content/uploads/egitimraporu.pdf

Roth, W.-M. (1993). Problem-centered learning or the integration of mathematics and science in a constructivist laboratory: A case study. *School Science and Mathematics, 93*, 113-122.

Roth, W.-M., & Bowen, G. M. (1994). Mathematization of experience in a grade 8 open-inquiry environment: An introduction to the representational practices of science. *Journal of Research in Science Teaching, 31*(3), 293-318.

Sanders, M. (2009). STEM, STEM Education, STEMmania. *Technology Teacher, 68*(4), 20-26.

Sarıer, Y. (2010). An evaluation of equal opportunities in education in the light of high school entrance exams (OKS-SBS) and PISA results. *Ahi Evran Üniversitesi Eğitim Fakültesi Dergisi, 11*(3), 107-129.

Schleigh, S. P., Bossé, M. J., & Lee, T. (2011). Redefining curriculum integration and professional development: In-service teachers as agents of change. *Current Issues in Education, 14*(3). Retrieved from http://cie.asu.edu/ojs/index.php/cieatasu/article/view/693

Scientific and Technological Research Council of Turkey. (2010). *2011-2016 bilim teknoloji insan kaynağı strateji belgesi* [2011-2016 science and technology human resources strategy document]. Ankara, Turkey: Author.

Serbest, A. H. (2005). *Vizyon 2023 teknoloji öngörü projesi: Eğitim ve insan kaynakları sonuç raporu ve strateji belgesi* [Vision 2023 technology foresight project: Education and human resources final report and strategy document]. Ankara, Turkey: Türkiye Bilimsel ve Teknik Araştırma Kurumu.

Skovsmose, O. (2010). Mathematics: A critical rationality? *Philosophy of Mathematics Education Journal*, *25*, #1.

Subotnik, R. F., Tai, R. H., Rickoff, R., & Almarode, J. (2010). Specialized public high schools of science, mathematics, and technology and the STEM pipeline: What do we know now and what will we know in five years? *Roeper Review, 32,* 7-16.

Tschannen-Moran, M., & McMaster, P. (2009). Sources of self-efficacy: Four professional development formats and their relationship to self-efficacy and implementation of a new teaching strategy. *The Elementary School Journal*, *110*, 228-245.

Turkish Academy of Sciences. (2010). *Bilim raporu* 2009 [Science report 2009]. Ankara, Turkey: Author.

Turkish Education Association. (2008). 80. yıl uluslararası eğitim forumu: Eğitim hakkı ve gelecek perspektifleri [80th anniversary international education forum: The right to education and perspectives on the future]. Ankara, Turkey: Author.

Turkish Education Association. (2010). *Ortaöğretime ve yükseköğretime geçis sistemi* [The transition system for secondary and higher education]. Ankara, Turkey: Author.

Tuzcu, G. (2006). *Eğitimde vizyon ve Avrupa Birliği'ne giriş süreci.* [Vision in education and membership process to European Union]. Ankara, Turkey: Türk Eğitim Derneği.

Uzun, A. (2006). Science and technology policy in Turkey: National strategies for innovation and change during the 1983–2003 period and beyond. *Scientometrics, 66*, 551-559.

Webb, J. (2011). *International mathematical olympiads results*. Retrieved from http://official.imo2011.nl/results.aspx

Williams, J. (2011). STEM education: Proceed with caution. *Design and Technology Education: An International Journal, 1*(16), 26-35.

Yağcı, Y. (2010). A different view of the Bologna process: The case of Turkey. *European Journal of Education, 45*(4), 588-600.