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Üstbiliş Destekli Tartışma Tabanlı Öğrenme Yaklaşımının Fizik Eğitiminde Kavramsal Değişim ve Üstbiliş Üzerine Etkisi

Erdoğan ÖZDEMİR[1], M. Sabri KOCAKÜLAH[2]

[1]Sivas Cumhuriyet Üniversitesi, Sağlık Hizmetleri Meslek Yüksekokulu, Sivas/Türkiye,
erdoganozdemir@cumhuriyet.edu.tr, https://orcid.org/0000-0001-7943-8002

[2]Balıkesir Üniversitesi, Necatibey Eğitim Fakültesi, Balıkesir/Türkiye,
sabriko@balikesir.edu.tr, https://orcid.org/0000-0002-4119-8477

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Özet –Kavramsal değişim süreci, öğrencinin ön kavramının bir problemi çözmede yetersiz kalması ile başlar. Öğrencinin bilimsel kavramı kabul ederek ön kavramını terk etmesi ile son bulur. Alanyazında kavramsal değişim kuramı ve değişkenleri detaylı bir şekilde tanımlanmış olmasına rağmen, kuramın sınıfta nasıl uygulanacağı ile ilgili bir boşluk vardır. Bu nedenle bu araştırmada, kavramsal değişim kuramına uygun üstbiliş stratejileri ile desteklenmiş tartışma tabanlı bir öğretim yaklaşımı tasarlanmış ve uygulanmıştır. Araştırma deseni olarak nicel baskın statülü karma model kullanılmıştır. Araştırmaya bir ortaöğretim kurumunun 10. sınıfında öğrenim gören 51 öğrenci katılmıştır. Araştırma verileri Özel Görelilik Kuramı Tanı Testi, Üstbiliş Özyeterlilik Ölçeği ve yarı yapılandırılmış görüşmeler ile toplanmıştır. Verilerin analizi sonucunda, uygulanan öğretimin öğrencilerin kavramsal değişimine olumlu katkısı olduğu sonucuna ulaşılmıştır. Uygulanan öğretimin öğrencilerin üstbilişine özellikle izleme, değerlendirme ve planlama boyutunda katkı sağladığı tespit edilmiştir.

Anahtar kelimeler: fizik öğretimi, özel görelilik kuramı, ön kavramlar, kavramsal değişim, üstbiliş.

Sorumlu yazar: Erdoğan ÖZDEMİR, Sivas Cumhuriyet Üniversitesi Sağlık Hizmetleri Meslek Yüksekokulu, 58140, Sivas/Türkiye.

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Geniş Özet

Giriş

Kavramsal değişim süreci, derste öğrencinin ön kavramının bir problemi çözmede yetersiz kalması ile başlar. Öğrencinin, öğretmen tarafından sunulan bilimsel kavramı akla yatkın işe yarar ve anlaşılır bulmasına bağlı olarak kabul etmesi, artık memnuniyetsizlik duyduğu ön kavramını terk etmesi ile son bulur (Posner vd. 1982). Pintrich vd. (1993), Posner vd. (1982)'nin bu kuramını öğrencilerin motivasyonunu ve kişisel özelliklerini dikkate almadığı gerekçesi ile eleştirmiştir. Bu eleştiri kavramsal değişimde motivasyonu ve bireysel özellikleri dikkate alan çalışmaların önünü açmıştır (Dole ve Sinatra,1998; Gregoire, 2003; Tyson vd.1997; Alsop ve Watts, 1997). Alanyazında kavramsal değişim kuramı ile ilgili bu kuramsal araştırmalara ek olarak öğretim içeren araştırmalar da yapılmıştır (Yıldız, 2008; Kapartzianis, 2012; Kural, 2015; Planinic vd. 2005; Ültay vd. 2015). Kavramsal değişim ile ilgili tüm bu araştırmalar incelendiğinde, öğrencilerin kavramsal değişim sırasında bilimsel kavramın nasıl farkına varacağı ve bu kavramın öğrencilere nasıl sunulması gerektiği üzerinde durulması gereken sorulardır. Zhou (2010) bu durumu göz önünde bulundurarak Bilim Öğretiminde Tartışma Yaklaşımını geliştirmiştir. Bu araştırmada ise Zhou (2010)'nun yaklaşımına öğrencilerin kendi düşüncelerini derinlemesine inceleyebilmelerini için üstbiliş eklenmiştir. Çünkü düşünmeyi düşünmek anlamına gelen üstbiliş kavramsal değişimin bir değişkeni olduğu gibi kavramsal değişimi doğrudan etkileyen motivasyonun da bir değişkenidir.

Bu araştırmada üstbiliş stratejilerinin eklenmesi ile birlikte Üstbiliş Destekli Tartışma Tabanlı Öğrenme Yaklaşımı adı verilen bu öğrenme yaklaşımının ortaöğretim öğrencilerinin özel görelilik kuramı ile ilgili kavramsal değişimine ve üstbilişine etkisi araştırılmıştır.

Yöntem

Araştırmada desen olarak nicel baskın statülü karma model kullanılmıştır. Araştırmanın veri toplama araçları öğretimden önce ve sonra eş zamanlı olarak uygulanmıştır.

Araştırmada kullanılan öğrenme yaklaşımı problemin sunulması, ön kavramların açığa çıkarılması, bilişsel çatışma yaratma, bilimsel bilginin inşası, bilimsel bilginin savunulması ve değerlendirme basamaklarından oluşmaktadır. Yaklaşıma üstbiliş stratejileri ise gruplara ayrılmış öğrencilere verilen izleme, planlama ve değerlendirme uzmanlıkları ile sağlanmıştır. Öğrenciler her hafta dönüşümlü olarak izleme, planlama ve değerlendirme kılavuzlarını kullanarak bu görevleri üstlenmiştir. Öğretim yaklaşımının basamakları her hafta özel görelilik kuramının bir konusuna uygulanmıştır. Öğretim altı hafta sürmüştür.

Araştırmanın örneklemi kolay ulaşılabilir örnekleme yöntemi ile belirlenmiştir. Araştırmaya Manisa ilindeki bir lisenin 10. sınıfında öğrenim gören yaşları 16 ile 17 arasında değişen 51 öğrenci katılmıştır.

Araştırmanın nitel verileri araştırmacılar tarafından geliştirilen üç aşamalı bir test olan "Özel Görelilik Kuramı Tanı Testi" ve "Yarı Yapılandırılmış Görüşme Formu" ile toplanmıştır. Araştırmanın nicel verileri ise Thomas, Anderson ve Nashon (2008) tarafından geliştirilen "Üstbiliş, Özyeterlilik ve Öğrenme Süreçleri Ölçeği" ile toplanmıştır.

Tanı testi verileri öğrencilerin üç aşamalı teste verdikleri yanıt kombinasyonlarına göre kategori ve alt kategorilere ayrılmıştır. Öğrencilerin öğretim öncesinde ve öğretim sonrasında bu kategorilere ve alt kategorilere dağılım frekansları oluşturulmuştur. Görüşme verileri ise benzer şekilde alt kategorilere ayrılmıştır. Öğrencilerin öğretim öncesindeki ve öğretim sonrasındaki alt kategori geçişleri bir diyagram ile sunulmuştur. Ölçek verileri ise betimleyici istatistik ve fark testleri kullanılarak analiz edilmiştir.

Bulgular

Özel Görelilik Kuramı Tanı Testi Bulguları

Tanı testi verilerinin analizi sonucunda altı kategori ve 20 alt kategori oluşturulmuştur. Öğretimin etkisi ile kategorilerdeki değişim genel olarak incelendiğinde öğretimin öğrencilerin kavram yanılgılarını, şanslı tahmin/düşük güven içeren yanıtlarını ve eksik kavramlarını azalttığı sonucuna ulaşılmıştır. Buna rağmen yapılan öğretimin öğrencilerin bilimsel kavramlarını ve yanlış pozitif kavramlarını artırdığı sonucuna ulaşılmaktadır. Bu sonuçlar yapılan öğretimin kavram yanılgıları ve eksik kavramları bilimsel kavramlara dönüştürmede etkili olduğunu göstermektedir. Buna ek olarak yanlış negatif yanıtların az olması ise elde edilen sonuçların güvenilir olduğunu göstermektedir.

Kavramlardaki değişimler tek tek incelendiğinde yapılan öğretimin en fazla ışık hızı ile ilgili doğru kavramın oluşmasına katkı sağladığı sonucuna ulaşılmıştır. Öğretim eşanlılık ile ilgili kavramsal değişime de olumlu yönde katkı sağlamıştır. Fakat öğretim yaklaşımının öğrencilerin enerji-kütle kavramları ile ilgili doğru kavramlarını kavram yanılgılarına dönüştürdüğü tespit edilmiştir.

Tanı testi ile elde edilen alt kategoriler ve değişimi ışık hızı, eşanlılık ve enerji-kütle başlıkları altında aşağıda açıklanmıştır.

Işık Hızı ile ilgili kavramsal değişim: Işık hızı kavramı ile ilgili üç alt kategori belirlenmiştir. Alt kategori 1 doğru bir açıklama, alt kategori 2 ise yanlış bir açıklama içermektedir. Öğretimin etkisi ile alt kategori 1'in artması ve alt kategori 2'nin azalması, öğrencilerin öğretimin etkisi ile ışık hızının gözlemcinin ve kaynağın hızından bağımsız olduğu bilgisini öğrendiklerini göstermektedir. Ayrıca alt kategori 3 yanlış bir açıklama içermektedir. Bu kategori öğretim sonrasında artmıştır. Bu durum öğretimin bazı öğrencilerde ışık hızı ile ilgili yanlış genellemelere sebep olduğu şeklinde yorumlanmıştır. Bu öğrenciler ışık hızının boşlukta sabit bir hızla ilerlemesi durumunu ışığın tüm ortamlarda aynı hızda ilerlemesi şeklinde genellemiştir.

Eşanlılık ile ilgili kavramsal değişim: Eşanlılık ile ilgili iki alt kategori belirlenmiştir. Alt kategori 6 doğru bir açıklama, alt kategori 7 ise yanlış bir açıklama içermektedir. Öğretimin etkisi ile alt kategori 6'nın artması, öğrencilerin bir gözlemciye göre aynı anda olan bir olayın başka bir gözlemciye göre aynı anda olmayabileceği bilgisini öğrendiklerini göstermektedir. Alt kategori 7 ile ilgili yanıtların artması ise öğretimin bazı öğrencilerde ışık hızı kaynağın hızından etkilenir fakat ihmal edilir düşüncesini oluşturduğu şeklinde yorumlanmıştır.

Enerji ve Kütle ile ilgili kavramsal değişim: Enerji ve kütle ile ilgili altı alt kategori belirlenmiştir. Alt kategori 16 doğru bir açıklama içermektedir. Alt kategori16'daki artış öğretimin etkisi ile öğrencilerin kütlesi olan cisimlerin ışık hızına ulaşamayacağı bilgisini öğrendiklerini göstermektedir. Alt kategori 15 doğru bir açıklama, alt kategori 18 ise yanlış bir açıklama içermektedir. Öğretimin etkisi ile alt kategori 15'in azalması ve alt kategori 18'nin artması, öğretimin bazı öğrencilerin sahip olduğu 'kütle değişmeyen madde miktarıdır' bilgisini 'ışık hızına yakın hız değerlerinde kinetik enerji kütleye dönüşür' düşüncesine dönüştürdüğünü göstermektedir. Tüm bunlara ek olarak öğretim sonrasında kategori 20'de artış tespit edilmiştir. Bu artış öğretimin öğrencilerde kuvvet uygulanarak hızlandırılan parçacıkların ulaşacakları hızın bir limiti olduğu bilgisini öğrendiklerini göstermektedir.

Yarı Yapılandırılmış Görüşme Verileri

Yarı yapılandırılmış görüşmelerden elde edilen alt kategoriler ve değişimi ışık hızı, eşanlılık ve enerji-kütle başlıkları altında aşağıda açıklanmıştır.

Işık Hızı ile ilgili kavramsal değişim: Altı öğrenci öğretimin etkisi ile Alt kategori 2'den, Alt kategori 1'e geçmiştir. Bu durum, öğretim öncesinde ışık hızının kaynağın ve gözlemcinin hızına bağlı olduğunu düşünen öğrencilerin öğretimin etkisi ile ışık hızının gözlemcinin ve kaynağın hızından bağımsız olduğunu düşündüklerini göstermektedir. Bir öğrenci öğretim öncesinde ve öğretim sonrasında Alt kategori 2'deki görüşü korumaya devam etmiştir. Bu öğrenci öğretim öncesinde de öğretim sonrasında da ışık hızının kaynağın ve gözlemcinin hızına bağlı olduğunu düşünmektedir.

Eşanlılık ile ilgili kavramsal değişim: Dört öğrenci öğretim öncesinde ve öğretim sonrasında alt kategori 6'ya uygun yanıt vermiştir. Bu öğrenciler öğretim öncesinde ve öğretim sonrasında bir gözlemciye göre aynı anda olan iki olayın bir başka gözlemciye göre aynı anda olmayabileceği bilgisine sahiptir. Üç öğrenci öğretimin etkisi ile Alt kategori 7'den Alt kategori 1'e geçmiştir. Bu durum öğretim öncesinde, ışık hızı kaynağın hızından etkilenir fakat ihmal edilir düşüncesine sahip olan öğrencilerin öğretimin etkisi ile ışık hızı gözlemcinin ve kaynağın hızından bağımsızdır düşüncesine sahip olduklarını göstermektedir.

Enerji-kütle ile ilgili kavramsal değişim: Üç öğrenci öğretim öncesinde ve öğretim sonrasında Alt kategori 15'e uygun yanıtını vermiştir. Bu kategoride yer alan öğrenciler öğretim öncesinde ve öğretim sonrasında kütle değişmeyen madde miktarıdır şeklindeki doğru yanıtlarını korumuştur. İki öğrenci öğretimin etkisi ile Alt kategori 15'den, Alt kategori 17'ye geçmiştir. Bu durum öğretim öncesinde, kütle değişmeyen madde miktarıdır düşüncesine sahip olan öğrencilerin öğretimin etkisi ile ışık hızına yakın hızlarda ilerleyen cisimlerin kütlelerini doğru ölçmek mümkün değildir düşüncesine dönüştüğünü göstermektedir.

Üstbiliş Özyeterlilik Ölçeği Bulguları

Üstbiliş Özyeterlilik Ölçeği bulguları incelendiğinde öğrencilerin öğretim sonrasındaki ortalama puanlarının öğretim öncesindeki ortalama puanlarından daha yüksek olduğu sonucuna ulaşılmaktadır. Fakat bu fark istatistiksel olarak anlamlı değildir. Ölçek faktörlerindeki değişim incelendiğinde ise öğrencilerin yapılandırmacı bağlantılama, izleme, değerlendirme ve planlama, konsantrasyon kontrolü faktörlerinde öğretim sonrasındaki ortalama puanlarının öğretim öncesindeki ortalama puanlarından yüksek olduğu sonucuna anlaşılmaktadır. Buna rağmen, öğrencilerin öğretim sonrasında fizik öğrenmede özyeterlilik ve öğrenme riskleri farkındalığı faktörlerinde ortalama puanlarında artışa rastlanmamıştır.

Sonuç ve Tartışma

Geliştirilen öğretim yaklaşımının öğrencilerin kavramsal değişimine olumlu katkısı olduğu sonucuna ulaşılmıştır. Bununla birlikte öğrencilerin, bir kavramı öğrenirken bilimsel olmayan ön kavramını koruyabildiği, bilimsel kavrama geçiş yapabildiği, iki kavramı bir arada kullanabildiği veya yeni bir bilimsel olmayan kavram oluşturabildiği tespit edilmiştir.

Araştırma sonuçları göz önünde bulundurularak modern fizik öğretiminde ilk olarak öğrencilerin sezgisel ve bilimsel olmayan düşüncelerinin klasik fizik kavramlarına dönüştürülmesi kavramsal değişimde bilişsel çatışmanın güçlü olması için ise sanal laboratuvar, simülasyon ve animasyon gibi öğretim materyallerinin geliştirilmesi önerilmektedir.

Araştırmanın öğretim yaklaşımının öğrencilerin üstbilişine olumlu katkısı olduğu sonucuna ulaşılmıştır. Fakat bu artış düşük düzeydedir. Ölçeğin alt boyutları incelendiğinde ise öğretim ile üstbiliş ölçeğinde sağlanan artışın büyük ölçüde ölçeğin izleme, değerlendirme ve planlama boyutundan kaynaklandığı anlaşılmıştır. Öğrencilerin üstbiliş düzeyini artırmak güç olduğu için araştırmacılara ve öğretmenlere öğretimde üstbiliş stratejilerini uzun süreli uygulamaları önerilmektedir.

The Effect of Metacognitive Supported Argument-Based Learning Approach on Conceptual Change and Metacognition in Physics Education

Erdoğan ÖZDEMİR[1], M. Sabri KOCAKÜLAH[2]

[1] Sivas Cumhuriyet University, Vocational School of Health Services, Sivas/Turkey,
erdoganozdemir@cumhuriyet.edu.tr, https://orcid.org/0000-0001-7943-8002

[2] Balıkesir University, Necatibey Faculty of Education, Balıkesir/Turkey,
sabriko@balikesir.edu.tr, https://orcid.org/0000-0002-4119-8477

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Abstract – The process of conceptual change begins when a preconception of a student fails to solve a problem. It ends when the student abandons this preconception and accepts a scientific concept. Although the conceptual theory of change and its variables are described in detail in the literature, there is a gap in how the theory can be applied in the classroom. For this reason, a course incorporating an argumentation approach supported with metacognitive strategies in accordance with the theory of conceptual change was designed and implemented for the subject of special relativity theory. A qualitatively dominant status mixed-method approach was used as the research design. The participants of the study were 51, 10th-grade students studying at a secondary school. Data were collected with qualitative and quantitative measurement tools. It was concluded that the applied course contributed positively to the students' conceptual changes and regulation of cognition (planning, monitoring, evaluating).

Key words: teaching physics, theory of special relativity, preconceptions, conceptual change, metacognition.

Corresponding author: Erdoğan ÖZDEMİR, Sivas Cumhuriyet University, Vocational School of Health Services, 58140 Sivas/Turkey, erdoganozdemir@cumhuriyet.edu.tr

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Introduction

The theory of conceptual change has been firstly proposed by Posner, Strike, Hewson and Gertzog, (1982). The inspiration for this theory comes from the theory of scientific revolution (Kuhn, 1970). Kuhn (1970) created the theory of scientific revolution to explain the process of scientific development. According to this theory, scientists enter a period of crisis due to the inability of the paradigms they create to explain the scientific facts. This crisis period motivates scientists to create a new paradigm. With the creation of a new paradigm, the period of crisis is overcome, and the scientific revolution is achieved. Posner et al. (1982) created the theory of conceptual change in a way that was similar to the theory of Kuhn (1970). Posner et al. (1982) have stated that students experience dissatisfaction with their preconceptions due to the inability of their non-scientific preconceptions to solve problems. According to this theory, it is emphasized that students who tend to maintain their preconceptions experience a conflict between the preconception and a scientific concept when the scientific concept is introduced. Posner et al. (1982) have described the conceptual change as a process of accommodation, which begins suddenly with cognitive conflict and progresses gradually. Posner et al. (1982) have also explained all the characteristics affecting conceptual change with the concept of conceptual ecology. Conceptual ecology is defined as everything that pre-exists in the cognitive structure of a person (Duit and Treagust 1998; Posner et al. 1982). Pintrich, Marx and Boyle (1993) have criticized the theory of conceptual change of Posner et al. (1982), claiming that it ignores students' motivation and personal characteristics. Pintrich et al. (1993) have emphasized in this critique that scientists' interests and objectives cannot represent students' interests and objectives, and the school environment cannot represent the scientific community too. It has been stated that the role of students in the school during learning is not the same as the role of scientists in the scientific community.

Motivation, on the other hand, is defined as activities that maintain learning behaviour (Palmer 2005). Motivation determines the direction of students' learning efforts in learning activities and tasks in the classroom environment, as well as affecting the adaptation of students to different learning tasks. The concept of motivation was first defined as a concept that depends on external factors (reward and good note-taking) with the effect of behavioural learning theory. However, it has been noticed that external factors such as rewards and getting good marks lose their effect in case of continuity. Therefore, motivation has been redefined depending on internal factors. According to this definition, it was emphasized that following cognitive processes, setting goals, determining metacognitive strategy increase motivation (Ryan and Deci, 1998; Eggen and Kauchak, 2001).

Pintrich et al. (1993) have defined the theory of conceptual change of Posner et al. (1982) as a cold conceptual change model to emphasize the mechanic's feature of this theory, which did not take into account motivation. The theory of conceptual change, which includes motivation, is expressed as a warm conceptual change because it considers students' personal characteristics (Pintrich, 2003). These critiques of Pintrich et al. (1993) about the conceptual change theory of Posner et al. (1982) have paved the way for studies that take into account personal characteristics such as the effect of fears and self-esteem etc. in conceptual change. This kind of researches was explained as follows.

In their Cognitive Reconstruction of Knowledge Model (CRKM), Dole and Sinatra (1998) have stressed that the strength, richness, coherence, as well as high commitment level of preconceptions, increase resistance to conceptual change. In Gregoire's (2003) Cognitive-Affective Model of Conceptual Change (CAMCC), it has been stated that concerns and fears can result in a strong rejection of new knowledge. Tyson, Venville, Harrison & Treagust (1997) have highlighted the importance of epistemology and ontology in conceptual change. Alsop and Watts (1997) have proposed a model with four components that emphasizes the importance of cognitive, affective, conative and self-esteem characteristics for conceptual change. The conative component in this model is explained in relation to the concept of metacognition. In addition to these theoretical studies on the theory of conceptual change in the literature, researches involving educational practice has also been conducted. When researches involving educational practice on the theory of conceptual change in science education is examined, it is understood that such research studies in which different instructional methods and techniques are implemented rather than research incorporating instructional models structured according to the theory of conceptual change. In these research studies, the effect of lessons involving the 5E teaching model (Yıldız 2008), instructional steps of conceptual change (Kapartzianis 2012; Kural 2015), cognitive conflict, changing concepts, analogy and Socratic dialogue techniques (Planinic et al. 2005), and texts for conceptual change (Ültay, Durukan and Ültay, 2015) on students' conceptual change have been investigated. In these studies, it was stated that the teaching made had a positive contribution to the conceptual change (Yıldız, 2008; Kapartzianis, 2012; Kural, 2015; Planinic et al. 2005; Ültay et al. 2015). Besides, it was stated that students tend to preserve their pre-concepts (Yıldız 2008; Kapartzianis, 2012; Planinic et al. 2005).

When the theoretical research on conceptual change is examined, it is understood that the components affecting conceptual change have been defined. In addition, various instructional methods and techniques that influence conceptual change positively have been determined in instructional educational research on conceptual change. However, these studies do not explain how students will adapt a scientific concept during conceptual change and how this concept should be presented to the students by considering their affective characteristics. Zhou (2010) has developed the argumentation approach in science education with this deficiency in mind. The most important feature of this approach is that it defines argumentation, which is known for its importance in science education, as an important variable of conceptual change (Osborne, Erduran and Simon, 2004). Zhou (2010) has explained the importance of argumentation in conceptual change by referring to Kuhn’s (1970) theory of scientific revolution, as other conceptual change theorists (Posner et al. 1982; Pintrich et al. 1993) have explained. Zhou (2010) has stated that a scientific revolution would be based on the discussion of different views of scientists. Therefore, Zhou (2010) argues that with the effective use of argumentation in the instructional environment, students' affective characteristics will be activated and their motivation will be improved. This thought inspired the authors of this study to add metacognition as a component in a conceptual change study. Therefore, in addition to Zhou’s (2010) approach, it was considered that scientists make scientific debates by understanding each other’s views, comparing these views with their own opinions and reflecting on their thoughts. This means that students should also aware of their views, examine their own and others’ views in a classroom environment. All these efforts indicate the importance of metacognition which should be incorporated into instruction during the teaching of scientific concepts.

Metacognition, defined as thinking about thinking, has two components: knowledge of cognition and regulation of cognition (Flavell 1979). Knowledge of cognition is defined as knowledge of one’s own cognitive capabilities and limitations. Regulation of cognition involves one’s contemplating his cognition, planning his activities, being aware of his learning performance, and evaluating his performance (Schraw, Gripped and Hartley, 2006). Metacognition is considered a component of conceptual change (Sinatra and Pintrich, 2003) as well as a component of motivation that directly affects conceptual change (Pintrich, et al. 1993). Conceptual change in which metacognition is taken into account has been defined by Sinatra and Pintrich (2003) as intentional conceptual change. The effects of lessons involving metacognitive strategies have been investigated in instructional educational research on metacognition in science and mathematics education (Kramarski and Mevarech 2003; Yıldız 2008; Seraphin, Philippoff, Kaupp & Vallin, 2012; Jayapraba 2013). In these studies, it has been shown that metacognition is effective in acquiring many skills. Metacognition gives students the ability to assess their cognitive strengths and weaknesses and teach them to use knowledge strategically (Seraphin et al. 2012). Moreover, metacognition is reported to be effective in allowing students to transfer information to graphic interpretation (Kramarski and Mevarech 2003) and in improving students’ academic success (Jayapraba 2013). Students’ use of their metacognitive abilities during teaching is another factor that improves the quality of teaching. However, it has been reported not to be easy for students to learn how to use their metacognitive abilities (Yıldız 2008).

This study is therefore aimed at developing and applying a teaching approach by the conceptual change theory by taking account of the contribution of many researchers from the past to the present. Moreover, it has not been adequately described in the literature how to apply teaching by the warm conceptual change theory in the classroom environment. Hence, Zhou's (2010) argumentation approach in science education was used as a basis for instructional design. By adding the use of metacognitive strategies to this design, because of the stated importance of metacognition in the conceptual change process, an instructional design called "metacognitive supported argument-based learning" was developed. Special relativity theory was taught to grade 10 students using this teaching approach. The subject of special relativity theory was selected because the theory of special relativity is a preliminary example (prototype) of a scientific revolution (Posner et al., 1982).

For the purpose of this research, the following research problems have been defined:

Are argumentation-based metacognitive strategies supported learning approach effective in transforming students' preconceptions into scientific concepts?

Are argumentation-based metacognitive strategies supported learning approach effective in increasing students' metacognition levels?

In the following section, the reviews of literature regarding the teaching of the special relativity theory and the contributions made by studies in the literature to the teaching of the special relativity theory are included.

Related Research about Special Relativity

For conceptual change to begin, students must not be able to solve problems with their preconceptions. Preconceptions of the students are important in creating the teaching content of the research. Hence, a systematic literature review was conducted to investigate students' preconceptions about the special relativity theory. Determined preconceptions related to the special relativity theory in the literature are given below.

Özcan (2017) has identified students' misconceptions about the concepts of reference systems, relative time and length in a study, in which 14 physics education students participated. Based on the results, it was stated that the students interpreted time dilation in the theory of special relativity not as a scientific reality, but as an optical illusion. Furthermore, it was emphasized that the students expressed that the mass of objects moving at speeds close to the speed of light increased and that the laws of physics were different in different reference systems. Panse, Ramadas and Kumar (1994) investigated the conceptual comprehension levels of students on the concepts of reference system and the simultaneity in their study, which included 111 graduate physics education students. In this study, it was emphasized that the students thought there was a limit to reference systems. Scherr, Shaffer & Vokos (2001) have also carried out a study on 800 social science and physics education students and examined their thoughts on the concepts of the theory of special relativity, simultaneity, and reference systems. In their study, it was concluded that most students learned the concept of simultaneity as the simultaneity of events measured by a single observer in a problem about the measurement of light signals. It was also stated that the students had difficulty understanding this concept because they attempted to explain this concept with the concept of absolute time that they had learned in classical physics. Additionally, it was determined that the students had difficulty understanding the concept of reference system. For this reason, it was stressed that the students could not comprehend that the results of an event were the same in different reference systems.

Selçuk (2011) has investigated the conceptual understanding levels of undergraduate students about the concepts of time, length, mass and density in the special relativity theory unit in her study, which included 185 physics and elementary education students. In this study, it was understood that the students thought that the duration of an event was equal for an observer placed in the stationary reference system and for another observer in the reference system moving at close to the speed of light. In addition to that, it was emphasized that the students thought that the change in the length of objects moving at speeds close to the speed of light happened in every direction. In the study, it was indicated that some of the students thought that the change in object lengths at speeds close to the speed of light was not actually happening, but that this change occurred perceptually. Furthermore, the students pointed out that the mass of an object moving at speeds close to the speed of light was greater than the stationary mass of the object. This idea led the students to misinterpret the change in densities of objects moving at speeds close to the speed of light. Selçuk and Çalışkan (2010) investigated the conceptual understanding levels of 46 physics education students about the theory of special relativity. In this study, the students interpreted the relativity of time as the slower operation of a mechanical clock at speeds close to the speed of light. In addition, it was expressed that the students were unable to internalize the change in lengths of objects at speeds close to the speed of light and attempted to solve problems related to this subject with the relative speed equations they had used in classical physics courses. Moreover, it was highlighted that the students had difficulty understanding the concept of reference system. In their study on 30 physics education students, Turgut, Gurbuz, Salar & Toman (2013) investigated the effect of modern physics course on students' conceptual understanding of the theory of special relativity. It was expressed that the lessons given during the study contributed to the understanding of the concept of relative time. It was revealed that the students had difficulty solving problems related to the relativity of length before and after teaching. The students expressed that the change in lengths of objects at speeds close to the speed of light was perceptual. Moreover, it was pointed out that the students thought that the mass of objects increased at speeds close to the speed of light after teaching. Özdemir, Kural and Kocakülah (2014) investigated the effect of constructivist teaching techniques on the conceptual change of the concepts of the theory of special relativity. The study had 50 tenth-grade students as participants. Based on the results of this study, it was concluded that the constructivist teaching techniques contributed to the conceptual understanding of the students. However, it was reported that the students solved problems related to the speed of light by adding the speed of the light source to or subtracting it from the speed of light. It was also stressed in the study that the students had difficulty learning the concepts of the reference system and simultaneity. Alvarado, Mora, and Reyes (2019) investigated the effect of peer instruction on students' beliefs and attitudes about special relativity theory. In the study in which 25 high school students participated, it was stated that peer education had a positive effect on students' beliefs and attitudes. In addition, it was determined in the study that the students had various alternative thoughts about the special theory of relativity. Some of the alternative concepts determined in the research are as follows; the speed of light is relative. Time does not depend on the speed of the observer. Students may have confusion applying the concept of relativistic mass in classical equations.

When the results of these studies are evaluated together, it is understood that the students' preconceptions related to the special relativity theory are shaped by the students' classical physics concepts and their incomplete classical physics knowledge. On account of this, problems that were used to teaching special relativity theory in this study are formed that students could not explain with classical physics knowledge and incomplete classical physics knowledge. Creating cognitive conflict was expected to be achieved on these problems.

While teaching content in this study has been arranged, factors that make teaching the theory difficult and recommendations for teaching the theory have been taken into account. The literature concerning these factors and recommendations are summarized below.

Kızılcık and Yavaş (2017) have carried out a study on 691 science-education and secondary-school students. They have examined the factors that make teaching the theory of special relativity difficult. Based on this study, those factors are expressed as the teaching of the theory is limited to mathematical problems and students' efforts to explain the theory of special relativity with classical knowledge of physics. Özcan (2011) has also carried out a study on 34 physics education students and examined their problem-solving approaches on the theory of special relativity. In that study, it was concluded that the students' problem-solving approaches were not scientific and strategically planned. It was emphasized in this study that the conceptual deficiencies of the students regarding the theory of special relativity caused them to be confused about reference systems. It was stated that this situation made it difficult for the students to solve problems related to the theory. Villani and Arruda (1998) have emphasized the importance of the history of science to teach effectively the theory of special relativity. In that study, it is stated that when students are taught the theory, they need to understand the differences between classical physics and modern physics, and the conceptual disconnections. To do that, it is stated that the original writings of scientists should be used in the instructional environment and class discussions about these writings should be carried out. Furthermore, the importance of talking about experiments and technological applications related to the theory of special relativity during lessons, as well as the use of visual materials, has been emphasized. This research includes various activities providing not only calculating mathematical equations but also, argumentation and classroom discourse. Besides, teaching content includes knowledge about science history and real situations about the theory. Alvarado (2017) conducted a study with 30 high school students. He compared the effect of peer instruction and traditional lecture on the teaching of special relativity theory. In the study, it was emphasized that the students had difficulty in correctly determining the variables of the theory-related formulas. It has been concluded that peer teaching is more effective than traditional teaching in teaching the theory. Also, the importance of persuasion discussions among students to overcome monotony in the teaching of the theory is emphasized. Croxton, V. & Kortemeyer, G. (2018) investigated the effect of the play A Slower Speed of Light, which was organized according to the Flipped method, on students' awareness, attitudes, and behaviours towards the special theory of relativity. In the study, it was stated that the game has positive effects on awareness, attitude, and motivation, although it has various limitations.

The related literature has been reflected in this study with a holistic approach by including the contradiction of classical-modern physics in the teaching content, considering the factors that make the teaching of the theory difficult and the suggestions that facilitate its teaching. In this way, rich content was formed for physics teachers that they can use in the teaching of special relativity theory. It is thought that this aspect of the research will contribute to the teaching of the theory.

Method

The mixed-method has used in this research. The mixed-method means that combining different quantitative and qualitative data collection tools in the same experimental research (Johnson, Onwuegbuzie and Collins, 2007). A convergent design which is one of the mixed-method research design was utilized in this study. According to this design, qualitative and quantitative data are collected and analysed concurrently and independently, and research data are interpreted and discussed with a convergent approach (Pardede, 2018).

The quantitative aspect of the research is more dominant than the qualitative aspect of research. Both qualitative and quantitative collection tools applied same time before and after the teaching application. For this reason, this research is the same time in terms of time and quantitative in terms of dominance (Venkatesh, Brown and Sullivan, 2016).

Table 1 Research implementation design

Before implementation	Implementation of teaching model	After implementation
The theory of special relativity–diagnostic test Semi-structured interview	Metacognitive Supported Argument-Based Learning Approach	The theory of special relativity–diagnostic test Semi-structured interview
Self-Efficacy and Metacognition Learning Inventory—Science (SEMLI-S) Scale		Self-Efficacy and Metacognition Learning Inventory—Science (SEMLI-S) Scale

To address the aim of the study, 10th-grade students participated in the course which took eight weeks. Data collection instruments were administered to the students before and after the course.

One of the reasons for using the mixed method in the study is overcoming the threat of validity problem which emerge when the researcher used only qualitative or only quantitative data. The other reason for using the mixed method in the study is to achieve a more widely reliable picture of students' conceptual change process and to investigate deeply this process (Johnson et al, 2007).

Research Sample

When the time this research was performed, content about special relativity theory was included in 10th-grade secondary school physics curriculum in Turkey (Turkey Ministry of National Education, 2008). Therefore, this research was conducted with students who studied special relativity unit in the 10th grade. The research sample was determined through the convenience sampling method (Onwuegbuzie and Collins, 2007). In the convenience sampling method, attention is paid to ensure that the sample is easily accessible. The researchers who use this method should consider its weakness in terms of the power of representing the research universe. Therefore, a school that represents average Turkish students' profile was selected from among the schools where the research was carried out. The features of the research school are as follows: A low achiever student in the sample scored 391 base points from the high school entrance exam and was settled in this school. A high achiever student can obtain a maximum of 500 points in this exam. It can be said that the students in the sample have got an average academic success in Turkey.

The school that the research was performed is located in the district where 41.135 people live in. The main livelihood of the people in this district is agriculture and animal husbandry. The people living in the city also represent an average socioeconomic level of Turkey.

The research sample consisted of 10th-grade students studying at a secondary school in a district of Manisa province in Turkey. The study included 51 students studying in Cohorts A and B of the school. A total of 27 students, including 12 females and 15 males, were studying in Cohort A, and a total of 24 students, including 14 females and 10 males, in Cohort B. The participants were between 16 and 17 years old.

Instructional Approach and Instructional Implementation

In this section, the instructional approach of the study, the implementation schedule of the course, and the instructional steps are presented.

Incorporation of metacognitive strategies in instructional approach: Zhou's (2010) Argumentation Approach in Science Education consists of six steps that are eliciting preconceptions, creating cognitive conflict, constructing scientific notion, defending scientific notion and evaluation. These steps of the instructional approach are described in detail in the following sections. The metacognitive strategies were incorporated into some of the steps of the designed instruction as described in Table 2.

Table 2 Incorporation of the Metacognitive Strategies in the Instructional Approach

Regulation of cognition	Group roles	Activities of Specialization	Instructional Material	Implementation Step
Monitoring	Monitoring Specialist	Follows the thoughts of group members and himself. Follows changes in the views of himself and his friends during their teamwork. Attempts to perform the tasks specified in the monitoring manual.	Monitoring Manuals	Eliciting preconceptions
Planning	Planning Specialist	Determines a strategy for problem solving. Defines a certain amount of time and the resources needed for the solution. Attempts to perform the tasks specified in the planning manual.	Planning Manuals	Defending scientific notion
Evaluation	Evaluation Specialist	Evaluates his and his group mates' thoughts during the course. Highlights the points that make learning difficult and those that make it easier for them. Attempts to perform the tasks specified in the evaluation manual.	Evaluation Manuals	Evaluation

Metacognitive strategies were integrated into the instructional approach together with group roles. In the teaching approach of the research, group roles were used as in cooperative learning (Yeşilyurt, 2019). With these roles and guides, how students can activate their metacognitions during their education has been made concrete. These roles constitute an important part of the research in terms of enabling students to use metacognitive strategies during teaching. With these group roles, it was intended to have the students monitor, plan and evaluate their cognitive experiences. The students in groups alternately assumed these roles every week. In this way, each student in the group has undertaken one of these roles at least once. The students who assumed these roles were called monitoring, planning and evaluation specialists. Monitoring, planning and evaluation manuals were designed to make the task easier for the students to perform the activities specified in the group roles. The guidelines presented in these manuals are given in Table 3.

Table 3 Guidelines in the Manuals

Monitoring Manual	Planning Manual	Evaluation Manual
Compare your own thoughts about the outcome of the problem with the opinions of your group mates. Ask your group mates questions to find out what they think about the problem. Let them explain the reasons behind their thoughts. During the group activity, stop the debate at certain intervals you consider appropriate and try to observe the changes in your friends’ ideas regarding the outcome of the problem. Ask questions. As a result of the group discussion, try to understand whether there are any changes in your ideas and your group mates’ ideas about the outcome of the problem. Think about the reasons for any changes you and your group mates may make in your opinions regarding the outcome of the problem at the end of the group debate.	Try to understand the problem with your group mates. Let your group mates make a prediction about solving the problem. Reach a consensus in a common prediction as a group. Set a deadline for solving the problem. Check out the information you’ve learned throughout the course to solve the problem with your group mates. If you need any further information necessary to solve the problem, identify it. As a group, solve the problem. Review your solution. If you have not been able to make adequate progress in solving the problem, modify your plan. Is your prediction correct?	Identify points where your group members are successful and unsuccessful during the study. Describe the learning difficulties you have experienced during your work as a group. Try to evaluate your group performance and the individual performances of the group members. Describe what the approach, hypothesis, and so forth you have set as a group contributes to solving problems. Describe how much you have learned as a group and as an individual during this course. Evaluate performance of yourself and your group mates in participating in the activities during this course. Think about what you need to do to improve your performance in the activities. Express the thoughts of your group mates and yourself at the beginning of the course. Think, by also considering the reasons, why your group mates and you have changed your thoughts during the course. Express the thoughts of your group mates and yourself at the end of the course.

These guidelines include activities to organize the cognitive knowledge of students during the course. These manuals were prepared as checklists. The student on duty of that week marked the activities (completed/not completed) using the guidelines presented in the manuals.

Preparation and implementation of the instructional approach: Preparations made before implementation of the course and the weeks of implementation, the class schedules, durations and the steps of implementation are shown in Table 4.

Table 4 Preparation and Implementation Schedule of the Course

Course Hour		Subjects	Duration	Implementation
		A. Pilot Study		
1	2	Speed of Light	90	Instructional steps were implemented for each subject.
2	2	Simultaneity	90	
3	2	Relativity of Time	90	
4	2	Relativity of Length	90	
5	2	Theory of Relativity, Mass and Energy	90	
		B. Preparation Studies Before the Actual Implementation		
1	2	Lesson on Conceptual Change Accommodation Conditions	90	Lesson on the terms of clarity, plausibility, dissatisfaction and usefulness
2	2	Establishment of the Instructional Order	90	Formation of instructional groups, determination of the seating arrangement of groups, announcement of the instructional approach and group roles
3	2	Practice Lesson: Serial and Parallel Connection of Batteries and Electromotive Force	90	Instructional steps
		C. Actual Implementation		
1	2	Speed of Light	90	Instructional steps were implemented for each subject.
2	2	Simultaneity	90	
3	2	Relativity of Time	90	
4	2	Relativity of Length	90	
5	2	Theory of Relativity, Mass and Energy	90	

Pilot study: A pilot study was carried out one year before the actual implementation. The pilot study was implemented in a secondary school in Balıkesir province, Turkey. The sample of the pilot study was selected by the convenient sampling method as in the actual implementation. The experience was gained in the pilot study was utilized in the actual implementation. Thanks to the pilot study, the timeline of the instructional steps were regulated, group roles were reviewed and strategies were developed to increase students' participation in the argumentations. Also, the actual implementation and instructional materials were reviewed.

Preparation studies before the actual implementation: Before the actual implementation, a lesson was carried out on conceptual change accommodation conditions, an instructional order was established, and a practice lesson was performed. The lesson on accommodation conditions included the terms of dissatisfaction, intelligibility, plausibility, and fruitfulness expressed by Posner et al. (1982) to explain the process of conceptual change. It was conducted in accordance with the instructional steps established by Hennessey (1993) and in a similar way to the lesson implemented by Yıldız (2008).

Establishment of the instructional order: Help was obtained from the teacher of the course when forming the instructional groups. The students were divided into three groups as low, moderate and high achieving according to their scores and academic achievements in the most recent school exam. Each group was assigned one student from the high-level group, one student from the low-level group, and two students from the moderate-level group. The students were asked to name their groups. During the instructional period, the student groups were seated together at fixed tables in the physics laboratory. The course was conducted with six groups. During the course, a projection device and a whiteboard were used. Before starting the course, the specifics of the course to be implemented for six weeks were explained to the students. Group roles and guidelines in the manuals were explained and every group member learned that they will work as monitoring, planning and evaluation specialists in their group by turns.

Practice lesson: In order for students to get used to the instructional model, a practice lesson was taught before the actual implementation. The grade 10 physics curriculum includes the topics of electromotive force and the serial and parallel connection of batteries in the electric unit before the theory of special relativity subject. These topics were taught by using the instructional approach adopted in this study.

Instructional steps

The teaching of each subject was completed in a total of two-course hours (90 minutes) each week following the instructional steps. These steps are briefly explained below. The course was taught by the first researcher.

Presenting problem context (10 minutes): This step of the course was initiated with a problem situation. Famous thought experiments and paradoxes related to the theory of special relativity, which were thought to be of interest to the students, were selected as problem contexts. The Michelson-Morley experiment, train paradox, twin paradox, ladder paradox and lighthouse paradox were used as problem contexts during the course. The problem contexts related to these subjects were projected on a screen. All students were asked to examine the problem contexts individually. The researcher initiated a class discussion to help students get a good understanding of the problem contexts by asking them a variety of questions. For example, a problem context involving the Michelson-Morley experiment was presented in a subject related to the speed of light. In this problem, the Michelson-Morley experiment was questioned in terms of its being carried out in the direction of the Earth’s rotation and a perpendicular direction to the Earth’s rotational direction.

Eliciting preconceptions (15 minutes): The students were asked to develop a solution for the problem context introduced in the previous step. All students then shared their suggestions for a solution with the group members. Then, the students were asked to develop a single solution proposal on behalf of the group as a result of this discussion. At this step, each group's monitoring specialist observed the views of himself and his group mates according to the steps expressed in the monitoring manual. The researcher wandered among the groups and asked questions aimed at eliciting the students' preconceptions for the solution of the problem. After the group discussion was over, the monitoring specialist of each group was given the floor. The monitoring specialists explained their solutions or solution proposals agreed by their groups to their classmates. Moreover, each monitoring specialist expressed his group's view, explaining what his group mates' thoughts were, and who changed or did not change their minds after the discussion. The views of the investigative group were summarized on the whiteboard.

Creating cognitive conflict (20 minutes): The correct answer to the problem situation presented to the students during the Presenting Problem Context step was expressed. At this step, simulations and animations on the internet about the problem context were used. Furthermore, it was ensured that the students noticed the discrepancy between the group opinion about the problem written on the whiteboard in the previous step and the outcome of the problem. At this point, a class discussion was held. During the discussion, the researcher posed several questions to determine whether the students experienced cognitive conflict. For instance, when talking about the speed of light, it is stated that the rays reaching the detector at the same time in any case and a simulation of the Michelson-Morley experiment (Virginia University Fowler's Physics Applets) was projected on the screen to perform it in a virtual environment.

Constructing scientific notions (20 minutes): The worksheets that the researcher prepared about the course subject were distributed to the students where each group received one pack. The students studied these worksheets as a group. The researcher wandered among the groups and answered the students' questions about the subject in the worksheets. Next, the scientific notions in the worksheets were briefly summarized by the researcher. Finally, the problem context mentioned at the beginning of the course was solved with the help of the scientific notions in the worksheets.

Defending scientific notion (15 minutes): Different problem about the concept that could be solved using scientific knowledge was projected on the screen. The students solved the problem according to the information given in the worksheets. At this step, the planning specialists of the groups established a solution plan for solving the problem with their group mates according to the steps expressed in the planning manual. The student groups worked to solve the problem. For instance, at this step, a problem was solved with regard to the speed of light in different environments from moving and stationary observers' perspectives.

Evaluation—compare, apply, metaknowledge (10 minutes): At this step, the students were asked to evaluate the conceptual change they experienced at the end of the one and half an hour instructional period. At this stage, the monitoring specialists explained the change in the views of the group members and their views about the concept they were taught according to the steps in the monitoring manual.

Data Collection Instruments of the Study

In this research, Theory of Special Relativity–Diagnostic Test which is a quantitative data collecting tool and Theory of Special Relativity–Semi-Structured Interview Form which is a qualitative data collection tool was used to determine students' conceptual change process. Self-Efficacy and Metacognition Learning Inventory—Science (SEMLI-S) which is also a quantitative data collecting tool was used to determine the change in students' metacognitive levels. These measurement tools are explained in detail below.

The theory of special relativity–diagnostic test: The reason for students' responses in multiple-choice tests cannot be understood. Knowing the reasons for students' answers to the questions is important for the detection of the conceptual change process. Moreover, whether students are confident in their answers or not is also important for the conceptual change process. Hence, three-tier tests are more useful than multiple-choice tests to detect students' conceptual change. Because students can express their responses and confidence levels in this test (Sari and Abdurrahman, 2019). In this research, a three-tier test was used for the investigation of students' conceptual change process in detail. The development process and features of the Theory of Special Relativity – Diagnostic Test are explained below.

During the development of the diagnostic test, three-tier test development stages were taken into account (Çetinkaya and Taş, 2016). Firstly, a concept map was developed to detect of test's content and scope to ensure content validity. In this process, the 10th-grade physics course curriculum (Turkey Ministry of National Education, 2008) and Physics for Scientists and Engineers with Modern Physics (Serway, 1996) which is one of the university physics textbooks was utilized for the design of the concept map. The basic concepts were determined with the map and one case was formed for each concept. There was a case for each question related to the concepts of the speed of light, classical time, simultaneity, relative time, relative length and mass/energy in the Theory of Special Relativity–Diagnostic Test.

The first stage of the questions was a multiple-choice concept question, and the second stage was a question of justification for this concept question. In the third stage of the questions, the students were asked to state their confidence in the accuracy of their answers to the first two questions. The test included a total of 14 questions, three questions about each of the concepts of the speed of light, relative length and mass/energy, two questions about each of the concepts of simultaneity and relative time, and one question about the classical concept of time. The KR-20 reliability coefficient of this test, developed by the researchers, was calculated as 0.88. The average difficulty index of the test was 0.52. The discrimination indices for the concept questions of the test ranged from 0.30 to 0.49 and those for the justification questions ranged from 0.30 and 0.44.

The theory of special relativity – semi-structured interview form: Although the theory of special relativity–diagnostic test is convenient for measurement of conceptual changes process, students' views are limited by the options of the questions. For this reason, interviews that students would be able to explain their views without limitation were conducted. Obtaining data with interviews would also increase reliability of the data obtained with the diagnostic test. In addition, students' views were analysed in detail thanks to interviews data. Development process and features of semi-structured interview form are explained below.

A case was given for each of the concepts of speed of light, classical time, simultaneity, relative time, relative length and mass/energy in the interview form as in the diagnostic test. Both of the data collection tools are parallel to the each other in terms of their content.

Firstly, semi-structured interview pre-form which include these concepts about special relativity was formed. This pre-form was evaluated in terms of comprehensibility and suitability to student level by a physics teacher who had been worked for a secondary school for ten years. The pre-form revised in line with the teacher's suggestions. Secondly, the pre-form was used for interviews of the pilot study. Pre-form was rearranged thanks to experiences which were gained in these interviews and finally, the theory of special relativity–semi-structured interview form was formed.

Two students from the high-level and low-level groups and four students from the moderate-level group were interviewed before and after the actual implementation. These students were selected from their groups (high, low and moderate level groups) randomly.

General achievements in physics were taken into account in dividing the students into groups. The physics teacher of the students helped in this regard. At this stage of the research, the purpose of determining the students in this way is to increase the power of qualitative research findings to represent the class. Each interview lasted 15–20 minutes.

Self-Efficacy and Metacognition Learning Inventory—Science (SEMLI-S): Metacognition is generally measured with Likert-type scales such as motivation, attitude, and self-efficacy. In this study, the Self-Efficacy and Metacognition Learning Inventory—Science (SEMLI-S) scale developed by Thomas, Anderson and Nashon (2008) was used. The scale consists of 30 five-point Likert type items. The items were gathered under 5 factors. These factors on the scale include constructivist connectivity, monitoring, evaluation and planning, science learning self-efficacy, learning risks awareness, and control of concentration. Linguistic equivalence, validity and reliability studies of the scale were carried out. Based on the verification of the data through confirmatory factor analysis, it was seen that the five-factor structure of the original scale also applied to the Turkish version of the scale. Factor loading values of the items ranged from 0.50 to 0.73, while item-total score correlations ranged from 0.39 to 0.65. The Cronbach-alpha coefficient calculated for the entire scale was 0.93 (Author, 2016).

Data Analysis

Data analysis approach that was used for mixed method (PCMH Research Methods Series, 2013) in this study was outlined below.

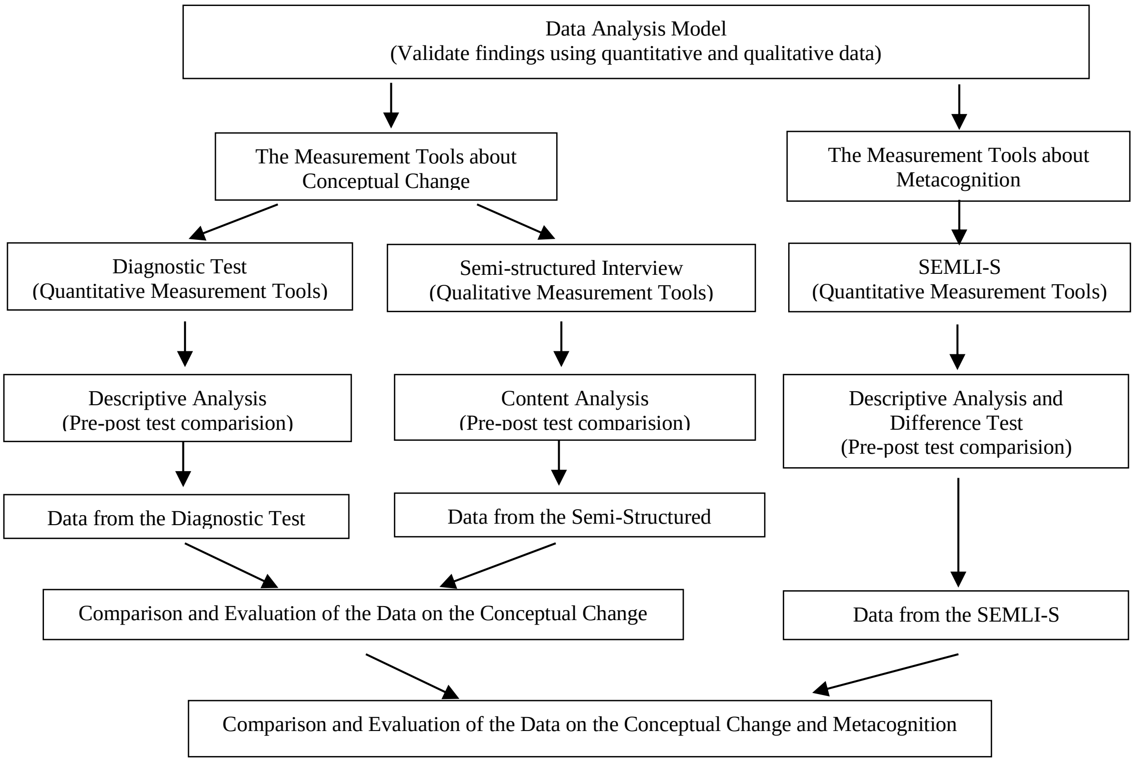

Figure 1 Data analysis approach for this study

Research data which are obtained by qualitative and quantitative data collection tools simultaneously were analysed independently each other. The research results were discussed and evaluated comparatively with a convergent approach.

Analysis of the theory of special relativity – diagnostic test data: Descriptive analysis was utilized for analysis of the theory of special relativity–diagnostic test. The data from the Theory of Special Relativity–Diagnostic Test were first divided into categories and subcategories. During the analysis of the Theory of Special Relativity–Diagnostic Test, the categories discussed by Hestenes and Halloun (1995) and used by Arslan, Çiğdemoğlu and Moseley (2012) were used, as shown in the table below.

Table 5 Categories for the Theory of Special Relativity – Diagnostic Test

Concept Question	Justification Question	Confidence in Accuracy	Categories
Correct	Correct	Confident	Scientific Concept
Correct	Incorrect	Confident	Misconception (False Positive)
Incorrect	Correct	Confident	Misconception (False Negative)
Incorrect	Incorrect	Confident	Misconception
Correct	Correct	Not confident	Lucky Guess, Low Confidence
Correct	Incorrect	Not confident	Incomplete concept
Incorrect	Correct	Not confident	Incomplete concept
Incorrect	Incorrect	Not confident	Incomplete concept

If the students accurately responded to the concept and justification questions and they were confident in their answers, they were considered within the category of scientific concept. The responses of the students collected under the false positive/false negative theme were considered as evidence for the internal validity of the scale (Hestenes and Halloun, 1995). If the students chose incorrect responses in the concept and justification questions and they were confident in their answers, they were considered within the category of misconception. If the students accurately answered the concept and justification questions but they were not confident in the accuracy of their answers, they were considered within the lucky guess or low confidence category (Arslan et al, 2012). The fact that the students' answer to one of the concept or justification questions was correct, or that they responded both the concept and justification questions incorrectly and they were not sure of their answer, they were considered within the category of incomplete concept. An incomplete concept represents a conceptual situation between a scientific concept and a misconception.

These categories contain different thoughts about the concepts of special relativity theory. Therefore, they were divided into subcategories as shown in the table below. In this study, only the data on the concepts of speed of light, simultaneity and energy/mass, which were inquired in the diagnostic test, were analysed. For this reason, the table below describes only the categories related to these concepts.

Table 6. Subcategories of Responses to the Theory of Special Relativity–Diagnostic Test*

Concept	Category	No	Subcategory	Concept	Category	No	Subcategory
Speed of Light	Scientific Concept/Lucky Guess Low Confidence	1	The speed of light is not affected by the speed of the observer and the source.	Energy/Mass	Scientific Concept/Lucky Guess Low Confidence	15	Mass is the amount of matter that does not change.
	Misconception / Incomplete Concept	2	The speed of light is affected by the speed of the source or the observer.		Scientific Concept/Lucky Guess Low Confidence	16	Objects with mass cannot reach the speed of light
	Misconception (False Positive) /Incomplete Concept	3	Light has the same velocity in all environments.		Misconception /Incomplete Concept	17	It is not possible to accurately measure the masses of objects moving at speeds close to the speed of light.
Simultaneity	Scientific Concept/Lucky Guess Low Confidence	6	Two events that are concurrent (simultaneous) according to one observer may not occur concurrently to another observer.		Misconception / Incomplete Concept	18	At speeds close to the speed of light, kinetic energy is converted into mass.
	Misconception (False Positive) / Incomplete Concept	7	The speed of light is affected by the speed of the source. But it is negligible.		Misconception / Incomplete Concept	19	The mass changes at speeds close to the speed of light.
					Misconception / Incomplete Concept	20	By doing work on an object, it is not possible to transfer more energy past a certain energy value.

* The numbers of the categories are not successive because this paper addresses categories related to the three questions of the Theory of Special Relativity–Diagnostic Test.

The research data on the students' distribution to above categories and subcategories before and after the course are presented in the findings section.

Analysis of the Semi-Structured Interview Form Data: Content analysis was used for analysis of the Semi-Structured Interview Form data. The interview records with students before and after the course were transcribed. Students' opinions repeated frequently and highlighted were taken into account. Reasonable and meaningful opinions of students converted into subcategories as in the diagnostic test.

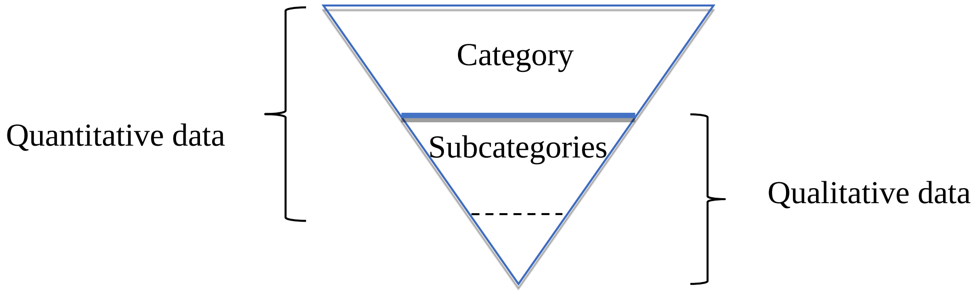

Figure 2 Combining qualitative and quantitative data

Qualitative data were used in the study to verify and elaborate the quantitative data as shown schematically in Figure 2. All of the subcategories that are determined by responses to interview form take place subcategories that are determined by the diagnostic test. In this case, it can be claimed that detected subcategories with these data collection tools are valid. The student opinions were distributed according to the subcategories shown in Table 6. The change between the students' response categories before the course and their categories after the course is shown schematically.

Analysis of the data from the self-efficacy and metacognition learning inventory—science (SEMLI-S) scale: Descriptive statistics and difference tests were utilized for analysis of Self-Efficacy and Metacognition Learning Inventory—Science (SEMLI-S) Scale data. Students' responses were scored as follows: never 1 point; rarely 2 point; occasionally 3 point; often 4 point and always 5 point. According to this scoring, maximum point to be obtained from this scale is 150. The data from this scale were analysed using the SPSS 16.0 statistical package platform. When analysing the scale data, first, the Shapiro-Wilk test of normality was carried out. Significance levels for the pre-test and post-test responses given to the Self-Efficacy and Metacognition Learning Inventory scale were calculated as .12 and .75 respectively. Since these values are greater than .05, it is assumed that the data is normally distributed. After the normal distribution of the data was tested, dependent samples t-test was applied to examine the change in scale scores depending on the instruction. In the t-test, the significance was tested at the 0.05 level. In addition, mean scores for the factors of the scale were determined. The average scores before the instruction and the average scores after the instruction were also compared.

Findings

Research results are presented in this section.

Findings Obtained Through the Theory of Special Relativity–Diagnostic Test

Below are the percentage distributions of the student responses obtained from the Theory of Special Relativity–Diagnostic Test before and after the course according to the categories.

Table 7 Distribution of the Students' Responses to the Categories

Concepts	Scientific Concept (%)		Misc. (False Positive) (%)		Misc. (False Negative) (%)		Misc. (%)		Lucky Guess Low confidence (%)		Incomplete Concept (Superficial Knowledge) (%)	
	BC	AC	BC	AC	BC	AC	BC	AC	BC	AC	BC	AC
Speed of Light	9	47	12	34	1	2	32	1	7	1	39	6
Simultaneity	2	31	15	33	7	7	7	7	11	4	58	18
Mass and Energy	15	13	2	14	1	0	14	21	12	5	33	25
Overall Average	9	30	10	27	3	3	18	10	10	3	43	16

Misconceptions are abbreviated as Misc. Before the course is abbreviated as BC and after the course is abbreviated as AC.

When the overall average in Table 7 is examined, it can be concluded that the course reduced the students' misconceptions, their responses with lucky guess/low confidence and their incomplete concepts, and it increased their scientific concepts and false positive concepts. This situation shows that the teaching approach was effective in transforming misconceptions and incomplete concepts into scientific concepts. In addition to that, the fact that the number of false negative responses was low shows that the results are reliable. Considering the changes in concepts on an individual basis, it was concluded that the course contributed most frequently to the formation of the correct concept related to the speed of light. The course also contributed positively to the conceptual change regarding simultaneity. However, the course caused the students' correct concepts related to the concepts of energy and mass to turn into misconceptions. It is therefore necessary to examine the categories in detail in order to understand the cause of this situation. Below are the percentage distributions of the student responses obtained from the Theory of Special Relativity–Diagnostic Test before and after the course according to the subcategories.

Table 8 Distribution of the Students' Responses into Subcategories

Concept	Subcategory	BC Response (%)	AC Response (%)
Speed of Light	1	15	47
	2	6	0
	3	11	22
Simultaneity	6	13	35
	7	14	19
Energy/Mass	15	50	12
	16	4	24
	17	6	4
	18	4	52
	19	6	4
	20	22	40

The conceptual changes about three subcategories were identified for the concept of speed of light. Descriptions of these subcategories are presented in Table 6. Subcategory 1 contains a correct explanation, and Subcategory 2 contains an incorrect explanation. The frequency of Subcategory 1 increased and the frequency of Subcategory 2 decreased, indicating that the students learned through the effect of the course that the speed of light was independent of the speed of the observer and the source. Moreover, Subcategory 3 contains an incorrect explanation. The frequency of this subcategory increased with the effect of the course, revealing that some of the students over-generalized the situation and incorrectly learned the case of the speed of light moving at a constant speed in space as the rule of light moves at the same speed in all environments.

The conceptual changes about two subcategories for the simultaneity were examined. Subcategory 6 contains a correct explanation, and Subcategory 7 contains an incorrect explanation. The increase of the frequency of Subcategory 6 due to the effect of the course indicates that the students learned that events that happened at the same time according to one observer may not happen at the same time according to another observer. The increase in the number of responses to Subcategory 7 suggests that, despite the impact of teaching, some of the students still hold the idea that 'the speed of light is affected by the speed of the source but is negligible'.

When the conceptual changes concerning six categories related to energy and mass concept were investigated, the increase in the frequency of Subcategory 16 that contains a correct explanation indicates that the course helped students learn that objects' masses could not reach the speed of light. Subcategory 15 contains another correct explanation, and Subcategory 18 contains an incorrect explanation. The decrease of the frequency of Subcategory 15 and the increase of the frequency of Subcategory 18 due to the effect of the course shows that the course transformed the idea that "mass is the amount of matter that does not change" some students had into the idea that "kinetic energy turns into mass at speeds close to the speed of light." On the other hand, one of the notable findings of this research is related to Subcategory 20. There is an increase in students' responses in this subcategory after teaching. This increase shows that the students have learned that there is a limit to the speed at which the particles accelerated by applying a force.

Findings Obtained through the Semi-Structured Interview Form

The findings obtained as a result of the interviews conducted within the scope of the research are presented in Figure 3.

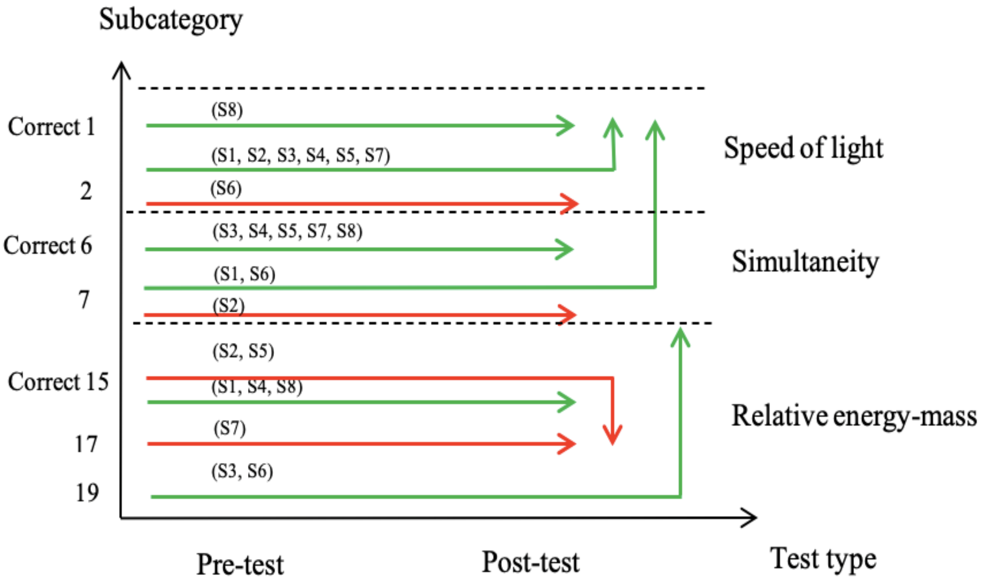

Figure 3 Changes in students' interview responses by subcategories

The codes in the form of S1, S2, etc. ... represent the students who were interviewed. The numbers in the form of 1, 2, 6, etc. ... in the vertical axis represent the subcategories explained in Table 6. Figure 3 specifies the students' response subcategories before and after the course. The change in the subcategories of each interviewed student before and after the course is expressed in lines. Red lines show the changes in subcategories in conceptually undesirable directions or subcategories that did not change after the course. However, green lines show the changes in the subcategories in the desired direction.

As the conceptual change about the speed of light is considered, six students (S1, S2, S3, S4, S5 and S7) switched from Subcategory 2 to Subcategory 1 due to the influence of the course. This indicates that the students who thought that the speed of light depended on the speed of the source and the observer before the course learned that the speed of light was independent of the speed of the observer and the speed of the source after the instruction. A student, who is S6, in Subcategory 2 maintained his view before and after the course. Before and after the course, this student believed that the speed of light depended on the speed of the source and the observer. Student 8 is the one who responded scientifically acceptable notions and took place in the Subcategory 1 in the pre and post interviews.

When the conceptual change about simultaneity is considered for students interviewed, five students (S3, S4, S5, S7 and S8) gave answers suitable for Subcategory 6 before and after the course. Before and after the course, these students maintained that two events that happened at the same time according to one observer may not happen at the same time according to another observer. Two students (S1 and S6) switched from Subcategory 7 to Subcategory 1 due to the influence of the course. This reveals that prior to the course, the students, who had the idea that the speed of light was affected by the speed of the source but this was negligible, learned that the speed of light was independent of the speed of the observer and the source after the instruction. However, student 2 maintained his view and responded that the speed of light was affected by the speed of the source despite teaching.

When students were interviewed about the concept of energy and mass, three of them (S1, S4 and S8) gave answers suitable for Subcategory 15 before and after the course. The students in this category maintained their scientifically correct views which meant that mass was the amount of matter that did not change. Two students (S2 and S5) switched from Subcategory 15 to Subcategory 17 after teaching. This shift indicates that the students who thought that mass was the amount of matter that did not change before the course altered their ideas due to the effect of the course and believed that it was not possible to measure accurately the mass of objects moving at speeds close to the speed of light. Two students (S3 and S6) switched from Subcategory 19 to Subcategory 15 after instruction. This shift indicates that the students, who had the idea that mass changed at speeds close to the speed of light before the course, started using the acceptable idea of 'mass was the amount of matter that did not change'. Only student 7 preserved his idea that it would not be possible to measure accurately the masses of objects moving at speeds close to the speed of light despite teaching. Below, Table 9 presents the correct interview responses of some of the students before and after the course.

Table 9 Samples from Students' Interview Responses

Concept	Student Code	Student Response Before the Course	Student Response After the Course
Speed of Light	S2	A stationary observer measures it as 3.108 m/s, but a moving observer measures it as 2.108 m/s or 5.108 m/s depending on the direction of the movement.	Don't they both make the same measurement? This is because the speed of light does not depend on the movement of the observer.
Simultaneity	S8	It flashes simultaneously for the first one (referring to the stationary observer). The other (referring to the moving observer) sees that D flashes earlier. This is because he is moving towards the flash.	I remember something like this in the train paradox presented in the class. Both observers came to the same conclusion. But one of them saw Y to flash earlier. It meant that the concept of simultaneity was relative.
Energy/Mass	S3	I think that at speeds close to the speed of light, the mass of objects decreases. Something with a mass that's fast passes very quickly. That's why we measure it lighter. But would it change or not? Is it okay if I don't say anything about it?	The mass of these protons increases. This is because we're moving so fast, you're accelerating it from E=mc2 and F=m.a. You're accelerating it. Its energy has to increase to the speed of light. Because c is constant, the energy is materializing or so. But the mass is actually the same.

The results obtained by the analysis of the interview data are similar to the results obtained by the analysis of the Diagnostic Test. The results obtained with both data collection tools show that the teaching approach of the research has certainly contributed, at least to some extent, to the conceptual change of students. Conceptual change data obtained by both data collection tools were evaluated and interpreted together in the next section.

Findings Obtained through the Self-Efficacy and Metacognition Learning Inventory—Science (SEMLI-S) Scale

The pre-test–post-test comparison of analysis results for the Self-Efficacy and Metacognition Learning Inventory Scale is shown in Table 10. Although 51 students participated in the study, three students were excluded from the scale because they answered only part of the scale. Therefore, 48 students were included in the analysis of the scale.

Table 10 Pre-test–post-test comparison of the Self-Efficacy and Metacognition Learning Inventory Scale

	Average	N	SD	df	t	p
Pre-test	98.02	48	17.16	47	-1.077	.287
Post-test	100.88	48	20.74			

The difference was not significant (significance level: p<.05) Maximum Score = 150

When the table above is examined, it is concluded that the average score of the students after the course was higher than their average scores before the course. However, this difference was not statistically significant.

Table 11 Average Scores for the Self-Efficacy and Metacognition Learning Inventory Scale's Dimensions

Scale Dimensions	Highest Score	Possible	Mean Score	Post-Test	Mean Score	Pre-Test
Constructivist Connectivity	35		23.35		22.02	
Monitoring, evaluation and planning	45		29.35		27.77	
Self-efficacy in physics learning	30		18.75		18.77	
Learning risks awareness	25		19.29		19.43	
Control of Concentration	15		10.14		10.02	
Total	150		100.88		98.02	

Analysis was carried out by tracking the differences in average scores for the scale factors. When Table 11 is examined, it is understood that the students' average constructivist connectivity, monitoring, evaluation and planning, control of concentration factor scores after the course were higher than their average scores before the course. Nevertheless, there was no improvement in the average scores of the students in the factors of self-efficacy in physics learning and learning risks awareness after the course.

In the next section, the findings of the research about conceptual change and metacognition are evaluated and discussed together in terms of the teaching approach adopted in this study.

Conclusion and Discussion

In this study, the effects of an original teaching approach in accordance with the conceptual change theory on conceptual change and metacognition were investigated. When the conceptual change-related findings of this study are examined as a whole, it is concluded that the metacognitive supported argument-based learning approach was effective in transforming the students' misconceptions and incomplete concepts about the theory of special relativity to scientific concepts. The results of the study are in line with the literature. It has been verified by many research studies that instructional approaches involving metacognition contribute to the learning of students (Ültay et al. 2015; Kural 2015; Yıldız, 2008; Seraphin et al. 2012; White and Frederiksen 1998; Anandaraj and Ramesh 2014; Jayapraba 2013).

The speed of light, as a concept, is a prerequisite for learning other concepts of the theory of special relativity (Scherr et al. 2001). It was concluded that the students' pre-conceptions about the speed of light before the course corresponded to the classical relative speed. A majority of the students calculated the speed of light prior to course based on the speed of the observer and the source in accordance with the Galilean transformation equations as reported by Özdemir et al. (2014). After the course, a majority of the students calculated the speed of light independently of the speed of the source and the observer. However, it was found that due to the effect of the course, some of the students adopted a new misconception about the speed of light. This new misconception was that light travels at the same speed in all environments. For these students, the fact that the speed of light was independent of the speed of the source and the observer turned, due to the instruction, into a general idea that light travelled at the same speed in every environment. This result shows that when an existing concept is displaced during conceptual change, it may be replaced by either the correct concept or another misconception. Another finding of the study about the speed of light was that the students used scientific concepts and misconceptions together. A student answered the question about the speed of light after the course as follows: "the speed of light is affected by the speed of the source and the observer." He answered the question about simultaneity as "The speed of light is affected by the speed of the source and the observer, but this effect is negligible." This situation has been interpreted as that students do not abandon their preconceptions during conceptual change and may use their preconceptions and scientific concepts together, depending on the situation (Yıldız, 2008).

Another reason why students use scientific concepts and misconceptions together is that students who find the process of cognitive conflict uncomfortable (Planinic et al. 2005; Kapartzianis, 2012) may not abandon the preconception but accept the scientific concept. When these findings of the study are considered as a whole, it can be stated that it is not an automatic process for conceptual change to abandon a misconception due to the inadequacy of it and to replace it with a scientific concept (Villani and Arruda, 1998).

Another outcome of the study was about the concept of simultaneity. The concept of simultaneity is closely related to the concept of the speed of light. Scherr et al. (2001) have expressed that insufficient knowledge about the concepts of reference systems and the speed of light leads to the lack of knowledge of simultaneity and impede the correct implementation of Lorentz transformation equations. Simultaneity is a concept that is not taught in classical physics (Scherr et al, 2001). In this study, it was concluded that the students who could not give correct answers and explanations about this concept before the course made correct explanations about this concept after teaching.

Finally, the conceptual change of the students regarding the concepts of energy and mass was examined in the study. Prior to the course, the students defined mass as the amount of matter that did not change. After the course, the students stated that mass was converted into energy at speeds close to the speed of light. This result means that the students had an increased number of misconceptions about mass at the end of the course. Turgut et al. (2013) have also reported that there is an increase after teaching in the number of students who think that mass increases at speeds close to the speed of light. Selçuk (2011) has stated that this misconception increases due to students' inaccurate generalizations and intuitive ideas. As an outcome of this study, the increase in the number of misconceptions related to the mass concept can be interpreted as that the students conceptualized "mass internal energy equivalence," which is used for referring to particles moving at speeds close to the speed of light, as a mass increase (Selçuk and Çalışkan, 2010). During the study, the students were not informed about a concept of mass that varied depending on speed, as stated in the 10th-Grade Physics Curriculum (2009), to avoid causing a misconception like "kinetic energy transforms into mass" (Turkey Ministry of National Education, 2008). But popular science publications, internet-based non-scientific sources, and even textbooks present information that mass varies depending on speed as also emphasized by Selçuk (2011). Such an unacceptable view, which affects the conceptual ecology of students, can be said to be directly related to the fact that the relationship between the rest mass energy (E_0) and the speed of light (c) in Einstein's equation of $\mathrm{E}_0 = \mathrm{mc}^2$ evokes the relationship between kinetic energy and speed in students' minds.

As a result of this study, four different situations have emerged for the students' conceptual change. Students can preserve their non-scientific preconceptions, switch to a scientific concept, use two concepts together, or create a new non-scientific concept when learning a concept. In which of these situations a student may be included after teaching varies depending on many variables. These variables create the conceptual ecology (Duit and

Treagust, 1998; Posner et al, 1982; Pintrich et al, 1993). To reduce the negative influence of conceptual ecology during teaching, it is proposed first to change students' concepts made up of intuitive, metaphysical or incomplete knowledge into classical physics concepts. Therefore, when teaching special relativity, it is suggested to incorporate the transformation of preconceptions to classical physics concepts into the instructional approach of this study as the first step. Moreover, the cognitive conflict needs to be strong to achieve conceptual change (Villani and Arruda, 1998). Since it is not possible to experiment on the subject of this study, teaching materials such as virtual laboratories, simulations and animations should be developed to teach the theory of special relativity. These materials can contribute to the implementation of cognitive conflict by improving the credibility of scientific knowledge.

In this research, it was concluded that there was an increase in the metacognition levels of students with the effect of teaching. However, this increase was low. When the sub-dimensions of the scale were examined, it was found that the increase observed in the metacognition scale scores was mainly due to the monitoring, evaluation and planning dimension of the scale. Considering that the strategies used in the teaching approach of the research are also related to these dimensions of metacognition, it can be said that the teaching made stimulates the students' organization of cognitive skills. It was observed that at the beginning of the course, the students were not very enthusiastic to implement metacognitive strategies and had difficulty using metacognitive strategies in the subsequent weeks. Based on the experiences obtained from this study, it was understood that it was not easy to activate the students' metacognitive abilities. Considering the difficulty of stimulating metacognition, which is also emphasized by other researchers (Yıldız, 2008; Özkan and Bümen, 2014), it can be argued that there will be significant improvements in metacognitive skills if teachers and researchers use metacognitive strategies for a long time in class discussions to allow students to be able to use their metacognitive strategies effectively. Additionally, it can also be said that the addition of the activities related to the sub-dimensions of metacognition such as constructivist connectivity, self-efficacy, awareness of learning risks and control of concentration to the teaching plan implemented in this study will strengthen teaching in terms of its contribution to metacognition.

When the results of this research are evaluated as a whole, the metacognitive supported argument-based learning approach contributed to the conceptual change of the students about special relativity theory and increased the students' metacognitive thinking skills especially for regulation of cognition. Additionally, this research contains information about how students will accept a scientific concept during conceptual change and how this concept should be presented to students. With this aspect of the study, it is thought that it will be beneficial for both researchers and teachers.

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