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INTEGRATION:

A STUDY OF READERS WITH MULTIPLE REPRESENTATIONS

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ABSTRACT

Learning with multiple representations requires the mental integration of corresponding information. The cognitive process of integration is mentally demanding, but can be assisted by different types of support. In this study, two different types of support for integration have been examined: first, learners can be supported by color coded corresponding elements across different representations (i.e. text and diagrams). Second, they can be supported by instruction which explicitly explains the importance of integration and encourages learners to actively integrate multiple representations. In this 2x2 experimental study, the efficacy of each type of support was measured based on their effects on cognitive load and learning outcomes. Results revealed that the color coding technique effectively guided learners' attention to the alternative representations. The instruction to integration helped learners to understand the relationship between different representations.

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Chapter 1

Introduction

In today's classroom, instructional materials are usually comprised of different forms of representations, such as text, pictures, animation, tables and formulas (Mayer, 2005). This development poses both challenges and opportunities for students across nearly any content domain. Knowledge acquisition from multiple representations requires learners to integrate emerging information from separate sources. It should be noted that the processes of integration can be very challenging for learners, especially novices, because they have to not only understand each of the given representation but also create referential connections between these representations (Seufert, T., & Brunken, R., 2006). In order to help novices effectively learn from multiple representations, the cognitive processes of representational integration need to be studied and understood better.

The existing models of multimedia learning have set up a starting point to understand learners' cognitive processes when learning from multiple representations (i.e. Mayer, 2005; Chandler & Sweller, 1991). A variety of instructional design principles have developed in line with this system. However, little attention has been paid to the learners' strategic and metacognitive processes that can support integration (Azevedo, 2005). To better understand the learners' processes in a multiple representation learning environment, this study investigated the effects of two factors that were hypothesized to support learners' integration across texts and diagrams: color coded corresponding elements between texts and diagrams and a priori direction to integrate texts and diagrams purposefully. In the remainder of this chapter, the empirical and theoretical literature relevant to the study of integration across multiple representations is reviewed and the implications of this body of work for the variables studied here are examined.

Learning from Multiple External Representation (MERs)

Defining Multiple External Representation (MERs)

External representations refer to the description or depiction of information represented to people. Descriptive representations consist of symbols, such as texts and formulas, whereas depiction representations consist of icons, like diagrams and illustrations. Generally speaking, descriptive and depictive representations have different uses allowing particular situations of strength depending on the representations. For example, descriptive representations are more helpful in expressing abstract knowledge, while depictive representations have the advantage of being informationally complete (Mayer, 2005).

Given the definition of external representations, multiple external representations refer to instructional materials that contain more than one representation. In an on-line tutorial course, for example, texts, diagrams, and animation are presented to learners in the same instructional material, which constitutes a multiple external representation environment. A biology lab manual that contains both texts and illustrations is also considered a multiple external representation environment. In today's classroom, students across different majors are frequently engage in learning with multiple representations when they learn from textbooks and classroom materials.

Integration of Multiple Representations

When students learn in multiple representation environments, they have to integrate the information from multiple representations. Integration can refer to the cognitive mapping processes that result in a coherent mental representation. In order to form a coherent mental representation, learners have to first understand the individual representation, then recognize the corresponding elements and structures of each representations and take a step further to generate referential connections between these representations (Seufert, 2006). In this process, the recognition of the correspondence in different representations requires two or more representations activated in learners' working memory simultaneously (van der Meij & de Jong 2006). Learners have to identify related elements and their relationship in each of the external representations to form a coherent mental representation within individual representation, and then map these structures onto one another to have an integrated mental representation that contains information from different sources and reflect the whole idea presented in multiple representations. In other words, in order to construct a coherent mental model, learners have to not only recognize and relate the surface features of different representations, but also to interpret the similarities and differences of corresponding features of the different representations (van der Meij & de Jong, 2006).

Taken together, integration leads to the learners' active construction of a coherent mental model. In order to construct a coherent mental model and gain deeper understanding, learners have to actively integrate information from different representations. Integration of textual and pictorial information into coherent mental representations is essential for better understanding and applying knowledge (Mayer, 2005). However, the integration process is cognitively demanding. The learning outcome can be largely influenced by learners' capabilities of creating connections between different representations and then constructing a coherent mental representation. Learners, especially novices, frequently have difficulty detecting relevant structures or elements in multiple representations, thus failing to integrate information from different representations (Ainsworth, 1999)

Past research on Learning from Multiple Representations (MERs)

Multiple Representations Enhance Learning

The general conclusion of empirical studies is that students do learn better from words and pictures than from words alone (Mayer, 2005). Started with Mayer and Gallini's (1990) work, this body of research has shown that the presentation of information in both visual (pictures or animations) and verbal (text or narration) forms generally increases the recall and transfer of knowledge by helping learners encode information in both visual and verbal forms and integrate these forms in long-term memory (Mayer, 2001).

Multiple representations can result in a deeper conceptual understanding and a higher flexibility in problem solving when learners integrate different representations. Multiple representations can play multiple roles in the learning process. First, MERs could provide complementary information and support complementary cognitive process.

Multiple representations can be used where single representation would be insufficient or too difficult to convey all the information or to cover every aspects of domain. Moreover, different representations may emphasize on different instructional purposes. Texts, for example, are better suitable for abstract contents, whereas pictures are better suitable to represent spatial relations. Additionally, the learners are given choices to work with their preferred type of representation and allowed to employ different strategies to perform on different types of tasks. Second, MERs can help learners to develop a more accurate understanding of a domain by using one representation to constrain the interpretation of a second representation. For example, one representation could be used to support the interpretation of a more abstract representation, or to constrain the possible misunderstanding of an unfamiliar representation. Third, MERs enable learners to construct deeper understanding of the instructional material. By providing learners with a rich source of domain representations, MERs encourage learners to construct references across these representations. Learners can benefit from the varying computational processes supported by different representations and then be able to draw different inferences from these different representations. This could lead to a higher level of organization and elaboration of incoming information and discovery of underlying principles (Ainsworth, 1999). This means that learners who integrate multiple representations would apply their knowledge better and more like to transfer the knowledge to novel situations.

Researchers have noticed the great potential of MERs is to promote integration and thus assist learning. This process of integration can be assisted by different instructional designs (e.g., hyperlinks, color coding) that decrease the demand required in the visual search for corresponding elements from different representations and therefore promote integration. In these optimal design conditions, integration can also be fostered in synchronized presentations and interactive manipulations (Bodermer, D., Ploetzver, R., Bruchmuller, K., & Hacker, S., 2005).

Bodemer et al. (2005), for example, found benefits of learning from MERs in a well-designed instructional environment which supported integration. The study investigated college students’ learning on Statistics. Participants were assigned to three conditions: non-integrated information, integrated information, and active integration of information. In the active integration of information condition, the participants were asked to actively relate the textual and algebraic elements to the elements of the visualizations by drag and drop. By doing so, the learners themselves had to actively construct an integrated format step by step. The posttests results revealed that learners who actively integrated different representations outperformed learners who were provided with non-integrated or pre-integrated representations.

In another study, Seufert and colleagues (2007) employed interactive hyperlinks to foster integration when learning from MERs. In the experiment condition, when learners clicked the hyperlinks, they were lead to the corresponding elements across representations. Participants in the hyperlink condition scored higher on recall and comprehension posttests than did participants who were provided the same MERs without hyperlinks.

Learning improves when multiple representations are integrated. Learning from MERs requires learners not only understand each of the given representations, but also learners must create referential connections between these representations as well. Only when learners integrate information from multiple representations can they construct a coherent mental model and thus gain conceptual understanding on complex topics (Bodemer, D., Ploetzner, R., Feuerlein, I., & Spada, H., 2004; Seufert, T., & Brunken, R., 2006).

Multiple Representations Do Not Guarantee Better Learning Outcomes

As concluded above, although MERs do have great potential to promote effective learning, the integration process is cognitively demanding. Learning with multiple representations is a highly demanding cognitive process because learners have to build referential connections between externally presented representations in order to construct a coherent mental representation. The whole integration process can put a large amount of cognitive demand on learners possibly hindering comprehension by overwhelming learners' working memory capacities, especially for novices. For example, novices might not be able to select the appropriate elements from each representation to build up inter-representational connections. Moreover, novices might be incapable of putting sets of related elements into organized chunks to reduce the demand on cognitive resources, because of their lack of organizational knowledge structure to do so (Seufert, T., Janen, I., & Brunken, R., 2007).

Many studies have shown that learners with low prior knowledge often have problem with the co-ordination and integration of MERs (Kozma & Russell, 1997). Kozma (1997) found that novices tend to focus on surface features rather than underlying principles, when comparing multiple representations of chemical reactions. They did not use different representations but rather concentrated only on one representation, often the more familiar or concrete representation. Additionally, a focus on the surface level feature rather than the deep, underlying principles or concepts made the integration process more difficult, because they often lack domain knowledge structures to organize the elements across representations. A number of studies have reported that novices have problems in either understanding individual representation or making connections across them (Goldman, 2003; Seufert et al., 2007; Bodermer et al., 2006; Tabachnech-Schijf, 1998; van der Meij & de Jong, 2006). The learning outcomes were found interacting with learners' characteristics, such as prior knowledge and the information presented by the tasks (Goldman, 2003).

Tabachneck-Schijf (1998), for example, examined the novices learning process while learning with multiple representations. In the study, the participants were asked to learn about the economics principles of supply and demand and solve problems which required learners to integrate the verbal and nonverbal representations. Participants were assigned to three different learning conditions according to the forms of nonverbal representations: a line graph, a data table, or algebraic expressions. The results showed that participants in all three conditions performed poorly in the problem solving test. Moreover, the think-aloud data revealed that participants tended to think through only one representation at a time, instead of integrating different representations and thinking about them as a whole. Even when the two representations were connected, the connections still tended to be constrained at a superficial level. Additionally, the study pointed out that the learners did not seem to realize they need to integrate MERs. These learners only switched between representations when faced with problems in understanding of the representation actually employed.

Whereas some researchers examined whether and how novices can benefit from MERs, Seufert et al. (2007) investigated the interaction between instructional design, learners' prior knowledge, and the complexity level of the tasks. Their study adopted interactive inter-representational hyperlinks to assist the visual search. Three studies were conducted to analyze the effectiveness of hyperlinks depending on the amount of intrinsic cognitive load, which is decided by the complexity of the learning tasks and also by the learners' prior knowledge. The first two studies found that the hyperlinks only worked for the less complex task. In the third study, the hyperlinks were found only to be effective for learners with high prior knowledge.

These studies showed that MERs have the potential to help learners to gain deeper understanding of the content. Unfortunately, for deeper understanding of content, learners have to identify corresponding elements or structures across different representations and form coherence of them. According to structure mapping theory (Gentner, 1983), coherence formation can be regarded as a process of mapping corresponding features and structures between multiple representations. This structure mapping process is crucial for effective learning in multimedia environments (Seufert et al., 2006). There is empirical evidence that complex mapping process is demanding cognitively and metacognitively. It requires learners be able and willing to conduct mapping strategy to integrate sources from different representations initiatively (Seufert et al., 2006). It should be noted that learners are not always aware of or capable of building connections across different representations and forming coherent knowledge structures.

In sum, these findings indicate that learners do not always benefit from MERs. In order to support learners gain more from multiple representations, various instructional designs were employed to better the way information is presented to reduce learners' cognitive demanding and to promote learning. However, even in a well-designed learning environment, learners still need to actively process the information from different representations (Azevedo, 2005; Mayer, 2005). The complex coherence formation process calls for great demand on learners' cognitive and metacognitive load (Ainsworth, 1999). To better address the cognitive demands that integration places on learners, first we need to take a close look at the existing cognitive models that provide the guidance and interpretation of the empirical work.

Theoretical Approaches to Understanding the Integration of MERs

Cognitive Models and Instructional Design Principles

The Cognitive Theory of Multimedia Learning (CTML) by Mayer (2005) and the Cognitive Load Theory (CLT) (e.g. Chandler & Sweller, 1991) are the most commonly recognized theories for learning from multiple representations. Despite the nontrivial differences between these two theories, they were both built upon the basic principles derived from other theoretical understanding of human minds, such as information processing theory (Baddeley, 1986) and Dual-Coding Theory (DCT) of working memory (Paivio, 1986). They each describe the characteristics and demands of learning from MERs with the underlying assumptions of limited working memory capacity and each sensory input channel.

Cognitive Theory of Multimedia Learning (CTML)

According to Cognitive Theory of Multimedia Learning (CTML) (Mayer, 2005), there are three important cognitive processes that learners have to engage in when integrating multiple representations: selecting relevant material, organizing selected material, and integrating selected material with prior knowledge. In the selecting stage, a learner attends to the text or images which are important to understand the domain knowledge. Once certain text or images are selected, they are brought to the working memory component. Then the learner tries to build up structural relations among the elements, this is the organization of selected material. Different knowledge structures can be adopted to organize the attended material. This cognitive process happens in learner's working memory component. After that, the learner has to integrate the selected material with his/her prior knowledge. This process involves building connections between incoming information and relevant portion of prior knowledge, which is activated from long-term memory and brought into the working memory component. For example, when a learner is learning the explanation of how human heart works. First, the learner has to attend to the appropriate elements in the text and images, like the terms and illustrations of different parts of human heart. Then these selected elements need to be organized into certain knowledge structure, for example, a cause-and-effect chain. After that, the learner must build up connections between the corresponding elements from the text and images as well as the relevant portions of prior knowledge in the long-term memory of human body.

All these steps take place in the working memory component of the cognitive system which has very limited capacity. It should be noted that the basic assumptions of

CTML are, that human information-processing system is a dual-channel, limited capacity, active-processing system.

These basic assumptions are derived from Paivio's (1986) Dual-Coding Theory (DCT), which basically postulates that both visual information (i.e. information from visual pictures and auditory pictures) and verbal information (i.e. information from written texts or spoken texts) are processed differently and along distinct channels. The cognitive architecture constitutes separate representations for individual channel. The information process in working memory happens in these two different representational memory systems when processing different types of information. In the long-term memory, both visual and verbal codes are used to process information respectively, including organizing, storing and retrieving of incoming information. In MER learning environments, effective learning occurs when a learner retains relevant information in each channel, organizes information in each channel into a coherent representation, and makes connections between corresponding representations. These connections can be made only if corresponding pictorial and verbal information is presented in working memory at the same time, also the connections with learners' prior knowledge have to be created.

One important assumption of DCT is the limited capacity of each channel and memory system. This assumption supports the idea that learners may learn more from MER because information is processed in two different channels. If visual information and verbal information are presented simultaneously, then learners might benefit from the expanded channel capacity, because visual and verbal information does not compete with each other for individual channel capacity. Otherwise, the working memory system could be easily overwhelmed when two separate representations need to be processed in the single channel.

The Cognitive Load Theory (CLT)

Similar to CTML, the Cognitive Load Theory (CLT) (Chandler & Sweller, 1991) also acknowledges the separate channels for dealing with auditory and visual material and emphasizes that human mind can only hold few elements in working memory. It elaborates on the implication of limited working memory capacity for instructional design and focuses on ways in which instruction imposes cognitive load on learners. The working memory is regarded as a limited set of mental resources that people use to encode, activate, store, and manipulate information while they perform cognitive tasks (Baddeley, 1986). In line with that, CLT is concerned with the manner in which this limited amount of cognitive resources is focused and used during learning and problem solving. CLT basically indicates three components of cognitive load: intrinsic cognitive load, extraneous cognitive load, and germane cognitive load.

First, intrinsic cognitive load is determined by the complexity of the content domain, as well as the learners’ characteristics, particularly the learner's prior knowledge. From the viewpoint of external representations, the complexity of the learning task depends on the amount of inter-related elements and to what extent these elements interact with each other as well as the number of different representations. That is, the intrinsic cognitive load increases when every additional representation is added to the interface, because learners will have to actively deal with all of these representations to gain a complete mental model. Taking from another perspective, even the same complex learning task could impose different amount of cognitive demand on people with different levels of prior knowledge. Learners with more prior knowledge with the content domain will be more able to chunk single elements into groups and map the new elements onto the existing internal knowledge structure. Therefore, their intrinsic cognitive load reduces (Seufert et al., 2007).

Secondly, extraneous cognitive load refers to the unnecessary cognitive demand caused by instructional design. It is not beneficial for learning (Chandler & Sweller, 1991). In the multiple representation learning environment, a wide range of instructional design were build upon the decrease of extraneous cognitive load, such as, split-attention effect, modality effect, redundancy effect, and expertise reversal effect (Sweller, 2005). Specifically, split-attention effect occurs when learners have to distribute attention to different forms of representations and search for corresponding elements and structures. The mental processes of integration can be demanding. Some empirical studies suggested that textual and pictorial information presented in a spatially integrated format resulted in a decrease of extraneous cognitive load and better learning (Chandler & Sweller 1991; Mayer, 2001). Different instructional designs on this effect, for example, hyperlinks (Seufert et al., 2006), color coding (Kalyuga et al., 1999), dragging and dropping box (Bodemer, 2004), find that making the connections between different representations explicit will effectively reduce the amount of extraneous cognitive load and therefore foster integration.

Finally, germane cognitive load refers to the type of load that comprises the processes of schema acquisition and automation. It is created by learners' effortful learning processes (Sweller, 2005). It can be learners' cognitive, metacognitive, or strategic processes of information. In most MERs learning environment, germane cognitive load is naturally high because of the requirement for learners to actively and effortfully construct a schema of the subject. The amount of germane cognitive load that learners spend on schema acquisition depends on the total amount of cognitive load as well as the amount of intrinsic cognitive load and extraneous cognitive load. Different instructional designs try to reduce extraneous load to free up resources for germane processes.

For the same purpose of reducing learners' extraneous cognitive load and inducing search for corresponding elements from different representations, Seufert et al. (2006), for example, examined two types of assisting strategies to support integration: surface feature level and deep structure level. In the surface feature condition, participants were helped with hyperlinks to recognize the corresponding elements and structures on a surface feather level (e.g., number, letter, line). In the deep structure condition, participants were explained the relationship of corresponding structures more or less explicitly. The effects on learning outcomes and cognitive load of both types of assistance were compared. Results show that integration can be efficiently supported by both types of help.

All three types of cognitive load are seen as additive and determine the total amount of cognitive load a learner experiences within a learning situation. Considering the nature of MERs, learners' limited cognitive load can easily be overloaded which might in turn impede effective learning. Therefore, different instructional designs try to reduce extraneous and intrinsic cognitive load to free up resources for germane processes and promote integration process.

In sum, three important implications can be drawn from CLT: (1) the instructional material containing text and diagrams might activate more learners' cognitive capacities than materials with text alone; (2) extraneous cognitive load can be reduced by hints across different representations since it aids learners' search and match process for correspondences; (3) prior knowledge plays a crucial role in intrinsic cognitive load and thus affect learners' available cognitive capabilities.

The Instructional Design Principles of Multiple Representations

Researchers have been attending to the design of multiple representational learning environments for decades. One of the fundamental theoretical guideline is that the instructional environment should be designed in light of how learners process information and acquire knowledge. Several important instructional design principles were drawn from this body of research, including modality principle, spatial contiguity principle, temporal contiguity principle, coherence principle, and split-attention principle (Mayer, 2005).

The split-attention principle states that it is important to avoid requiring learners to split their attention mentally between formats, or to mentally integrate information from multiple sources. In other words, instructional material should be designed in a way that disparate sources of information can be physically and temporally integrated, thus eliminating the need for learners to engage in mental integration. By doing so, extraneous cognitive load is reduced to free up resources for schema acquisition. Additionally, the consequence of extraneous cognitive load can be alleviated by increasing effective working memory capacity, for example, presenting information in a mixed visual and auditory mode rather than a single mode (Swell, 2005). Mayer and Moreno's (1998) study on college students’ integration of visual representations with different forms of discourses (written or auditory texts) found that the group with auditory text scored higher on the post-test. It was hypothesized that the reason this group outperformed the written texts group was that auditory texts were easier to integrate with visual animations and therefore improved learning. This finding is consistent with the split-attention effect, that is, if using spoken text instead of written text, learners integrate two representations better when they are not competing for attention within single channel.

Split-attention effect occurs when two or more sources of visual information must be processed simultaneously in order to make sense of the learning material. In order to avoid reducing the unnecessary cognitive load imposed on learners because of the particular format, the instructional material can be presented in an integrated format in which the diagram and text are physically integrated eliminating the need to search for relation between them. Researchers are working on the designs that could reduce the extraneous cognitive load posed by mentally integration processes. For example, Bodemer et al. (2004) examined the effect of integrated format of instructional material. The first experiment was conducted to compare the learning outcome between an integrated format of representations and a split-source format of representations. The result revealed that the integrated format facilitated learning significantly more than the split-source format. Bodemer and colleagues also found that learners benefited from MREs when they learned in an interactive, dynamic instructional environment which was designed to support integration. In Bodemer's second experiment (2004), participants were divided into three conditions with different formats of representation: split-source format, pre-integrated format, and active integrated format. In the active integration condition, participants were asked to label the diagrams themselves by dragging and dropping the selected pieces of the text and algebraic expressions. The participants in the active integrated format condition outperformed participants in the other two conditions.

Likewise, Kalyuga and colleagues (1999) conducted two experiments to investigate alternatives to split-attention instructional designs. Experiment 1 uses auditory presentation of text (instead of visual presentations of text) to increase cognitive resources. In experiment 2, a color coding technique is employed to reduce extraneous cognitive load and induce search for corresponding elements from different representations. The result shows that learners' mental load in the instructional design condition is reduced. Participants in the color coding condition score higher in the post test than the control group.

In summary, instructional designs that reduce the cognitive effort required for learners to select the important elements from representations and determine the element correspondence between representations should allow additional resources to be available for the cognitive tasks of comprehending and integrating representations. Consequently, these designs should lead to improved learning from MERs. In this study, we used color coding to reduce the effort required for selecting and matching elements in redundant text and diagrams. Color coding consisted of highlighting corresponding elements in texts and diagrams with the same color. By comparing learners who studied highlighted materials to participants whose materials were not highlighted, this study tests the hypothesis that color coding can enhance student learning from instructional materials that contain

MERs.

As stated previously, considering the integration process is highly demanding, learners are not always aware of or capable of building connections across different representations and forming coherent knowledge structures, even given the most optimal instructional design. The complex mapping process calls for great demand on learners' cognitive and metacognitive load (Ainsworth, 1999). Whereas the research reviewed thus far has used the framework of CTML and CTL to develop principles of instructional design, other researchers have investigated learners' strategies and metacognitive process while learning from MERs.

Learners' Processes in the Integration of MERs

As we reviewed in previous part, a large amount of research has been conducted to explore various cognitive processing and instructional design aspects of learning with MER environments. However, the role of the learner in those cognitive processes in the integration process has not been adequately addressed. For example, in a multimedia learning environment, how do learners select appropriate elements from different representations and which learning strategies do they adopt to organize the selected material? Hypermedia learning environments are effective to the extent that they can provide adaptive, individualized instruction based on the understanding of learner characteristics, systems features, and mediating learning processes interact with particular context. Learners' cognitive processes are influenced not only by instructional representations, but also by how learners process these instructional representations.

Therefore, learners’ self regulation, the effects of specific strategies, and the metacognitive and strategic process of integration need to be understood to reach the full potential of learning with MERs.

With respect to strategy use while learning from MERs, researchers believe that the design of different representations can affect how people process the MERs. For example, Van Meter (2001) has conducted a study with elementary school students regarding the effect of drawing strategy in the integration of verbal and pictorial representations. The study compared the learning outcomes across three conditions: the drawing strategy without support, with support of provided illustrations, or with the support of both illustrations and guided prompting questions. The result revealed that the participants in the supported drawing condition scored higher on a recall posttest than did participants in the control condition. Think aloud results showed that participants who used drawing strategy tended to engage in more self-monitoring behavior than did participants who did not draw. Similarly, Butcher (2006) studied learner's self-explanations strategy while learning from text and diagrams. The study compared the learning outcome across three conditions: text alone, text with simplified diagrams, or text with complex diagrams. The think-aloud data showed that participants who studied simplified diagrams scored higher on posttests than did participants in the text only condition. In addition, protocol analyses indicated that simplified diagrams most strongly supported information integration. It also suggested that the power of visual representations might lie in their ability to support learners’ strategy use rather than the characteristics of the medium itself.

While some researchers examined the influence of specific strategies on learning from text and diagrams, others took a view through Self-Regulated Learning (SRL) model. Azevedo et al. (e.g., Azevedo, 2004) have argued that a self-regulated learning model can serve as a guiding theoretical framework to examine learners' processes when learning from MERs. Derived from Self-Regulated models (Winne, 2001; Winne & Hadwin, 1998), where a recursive cycle of learning activities were concluded into four basic stages: task definition, goal setting and planning, enacting study tactics and strategies, and metacognitively adaptation, Azevedo and his colleagues proposed a model of self-regulated learning in hypermedia learning environments (e.g., Azevedo et al. 2004; Azevedo et al., 2005). The model took the first step toward examining cognitive processes through metacognitive lenses. According to the model, the self-paced feature of multimedia learning environments require the learner to regulate his or her learning processes whereby they set goals for their learning and then attempt to plan, monitor, control and evaluate their cognition, motivation, behavior, and context. Azevedo and colleagues have conducted a series of research showing that students who employ more effective self-regulatory processes benefit more from hypermedia learning environments. For example, in one study, Azevedo, Guthrie, & Seibert (2004) have examined the effects of college students' self-regulatory behavior in learning about the circulatory system in hypermedia environments. Pretest, posttest, and verbal protocol data were collected to measure students' shifts of conceptual understanding and the self-regulatory variables associated with these shifts. The study found that students who showed a large gain in their conceptual understanding were much better at regulating their learning than students who showed relatively little gain. In general, students who showed large gains tended to use more effective strategies, planned their learning by creating sub-goals and activating prior knowledge, monitoring their emerging understanding, and planned their time and effort.

Azevedo et al. (2005) also have examined the role of different scaffolding instructional interventions in facilitating learners' self-regulated behavior when learning from MERs. The effects of two different types of scaffolds were investigated: fixed scaffolds and adaptive scaffolds. Fixed scaffolds are static, providing students with general instructions (e.g., learning goals, list of strategies, and domain-specific questions). In contrast, adaptive scaffolds require a human tutor to assist students to learn, helping them generate goals, develop plans and use effective strategies at an individual level. In the study, learners were assigned to three conditions: fixed scaffolds, adaptive scaffolds, and no scaffolding. The posttest measurements revealed that learners who were provided adaptive scaffolds had the greatest gain in their mental model of the circulatory system and scored highest on an illustration labeling task. The think aloud protocols revealed that learners in the adaptive scaffold condition were most likely to evaluate their understanding while learners in the fixed scaffold condition more frequently focused on monitoring evaluations on the adequacy of the content. Additionally, learners in the no scaffold condition used strategies, such as note-taking and rereading strategies, more frequently than did learners in the other two scaffolding conditions.

Taken together, this body of research showed that learners' strategic and metacognitive processes influence how they manage multiple representations. Moreover, they also revealed that these learners' processes can be assisted by various supports to reach the potential benefit of MERs.

As discussed earlier, the major challenge of learning from MERs is that the integration of MERs is a highly demanding cognitive task, which is limited by the cognitive resources of the human mind. In addition to the cognitive process, researchers have suggested that metacognition also plays a central role in the integration of MERs. Mayer (2005), for example, pointed out that metacognitive strategies are particularly important in multimedia learning. Metacognitive strategies refer to the “techniques for allocating, monitoring, coordinating, and adjusting these limited cognitive resources” (Mayer, 2005). In other words, if we look the equation from learners' side, learners could be taught learning strategies and metacognitive strategies to enhance their awareness of integration and to facilitate their understanding of how to integrate information from separate sources.

In this study, we intend to encourage learners to systematically integrate different representations by giving them a general instruction about the importance of integrating multiple representations and how to integrate. In order to initiate active processes of coherence formation, participants were specifically taught to set up a goal of integrating multiple representations. The purpose of this general instruction was to facilitate learners' metacognitive monitoring of the integration process.

Limitations of past research and rationale for the current study

Some empirical studies suggested that textual and pictorial information presented in a spatially integrated format resulted in a decrease of extraneous cognitive load and better learning (Chandler & Sweller, 1991; Mayer, 2001). Other studies suggested that various symbolic conventions, like color-coding (using the same color for corresponding entities in different representations), would avoid extensive search and match process. Thus this would reduce extraneous cognitive load and maximize the acquisition of new schema. (Kalyuga, 1999; Kozma, 2003).

There are several ways to make evident corresponding elements to avoid extensive search and match process as well as to suggest integration. Such aids may include color, shape, or nonverbal signs. In Seufert study (2006), for example, color-coding was deployed to guide learners' attention to relevant parts of different representations. It is reasonable to suggest that color-coding of the corresponding elements of the text and diagram should produce an effect of reducing search and its associated cognitive load. Coloring elements of a diagram in the same colors as corresponding textual elements should reduce an unnecessary working memory load by reducing search processes involved with split source instructional formats. The released cognitive resources could be devoted to schema acquisition. Similarly, Kozma (1997) suggested that surface features (line, number, letter) can be designed to help students connect MERs to underlying principles. By using representations with shared features – same color as the corresponding elements ---- the design helps students to link various representations together. In creating these links, learners will be able to map knowledge gained from one representation on another representation to construct a comprehensive and accurate understanding from the individual incomplete representation.

While these instructional suggestions have the potential to reduce cognitive load, they do not directly support learners in constructing meaningful knowledge. Learners may nevertheless remain rather passive, concentrating on surface features of the visualizations and they may still be unable to mentally process and integrate the represented information in an adequate way. There is a large body of research addressing the instructional design principles in learning with hypermedia environment. However, little has been conducted to examine the students' self-regulated processes and metacognition during the integration of multiple representations. The question of how instructional aids help facilitate integration during learning with MERs at the surface level (color-coding) remains unanswered.

In this study, we manipulated students’ goals in this study by explicitly telling participants about the presence of both text and diagrams in the instructional materials and the importance of studying and integrating the representations. This manipulation tested the hypothesis that learners, who are aware of the benefit to learning of integrating representations will be more likely to do so and subsequently, will acquire more knowledge in comparison to learners who were not made aware of these benefits through instruction.

This study employed a 2x2 design in which both color coding and instruction to integrating were manipulated. One-half of the participants studied instructional materials in which corresponding text and diagram elements were highlighted with the same color background. In addition, one-half of the participants were told, before studying the materials that they should try to understand how the text and diagrams were related and that this would improve their understanding of the material. The color coding manipulation tested the effects of this design element on learners' perceptions of cognitive load and knowledge outcomes. The manipulation of task instructions tested whether increasing learners' awareness of the benefits to integrating MERs would affect performance on the knowledge-based outcome measures.

By including a condition that combined color coding with the goal setting manipulation, this study tested the degree to which the enhanced instructional design and metacognitive instructions combined to influence learning outcomes.

We hypothesized that the two variables tested in this study would cause learners to comprehend and integrate representations. Accordingly, we designed a posttest measure to assess the degree to which participants understood each representation separately as well as the connections between representations. This posttest was a multiple-choice test of reasoning within the verbal text representations, within the diagram representations, and between the two representations. Each type of items consisted of two forms of tasks: factual recall tasks and knowledge transfer tasks. For the factual recall tasks, the learners were required to recognize terms and statements that were explicitly stated in the texts as well as in the diagrams. Knowledge transfer tasks were measured by questions that required learners to apply inferred concepts to situations that were not directly mentioned in the material but could be derived from the learning material.

The specific research hypotheses tested in this study were:

1. Participants who study instructional material with color coding would obtain higher scores on diagram-only and text-diagram post-test items than would participants who did not study color coded materials.

2. Participants who were instructed to integrate representations would obtain high scores on diagram-only and text-diagram post-test items than would participants who did not receive these instructions.

3. There would not be effects of either color coding or integration instructions on text only posttest items.

4. Participants who both studied color coded material and received integration instructions would have higher diagram-only and text-diagram scores than any other group. The combination of both types of manipulation (color coding and integration instruction) would result in better learning outcomes and lower perceptions of cognitive load.

5. Participants who studies color coded material would have lower perceptions of cognitive load than would participants whose material was not color coded.

Chapter 2

Methods

Participants

118 students (117 undergraduate students and 1 graduate student) participated in this study. Participants were recruited from an undergraduate Educational Psychology course and were offered 6 points of extra credit for the course they were recruited from for volunteering in the study. The participants were from diversified educational background and were expected to have limited prior knowledge in the subject matter of predetermined experimental content. Learner's prior knowledge was determined by a 20-item multiple-choice pretest as well as by their majors. Of the 118 students (96 were female) who participated in the study, 74 were in their first year, 29 were in their second year, 11 in their third year, 3 in their fourth year, and 1 was in graduate level. Almost all the students were full time enrolled (99.2%). The majority of the students (97.5%) were between the ages of 18 and 22 with the remaining between 23 and 30. The mean GPA was 3.35.

Design

In order to test the hypotheses, a 2x2 factor design was used with the independent variables of instruction to integrate (with, without) and color coding (with, without).

Participants were randomly assigned to one of these four conditions (about 30 participants for each condition). The dependent variables were learning outcome measured by a 42-multiple-choice knowledge post-test (maximum score of 45 points) and cognitive load. Learners' prior knowledge was assessed in a 20-item pretest (maximum score of 20 points).

In the color coding condition, the corresponding elements of diagrams and texts were color coded with the same unique color to reduce search and match process for correspondence across different representations. Students who were not in the color coding condition were given texts and diagram labels only in black font. In the instructions with integration direction condition, participants were told about the importance of integrating texts and diagrams and given a goal to do so, whereas in the control group, participants did not receive information about the importance of integrating texts and diagrams or a goal to do so.

Materials

Integration Instruction

Participants were given instruction prior to reading the text, depending on the condition they were either given direction to integrate the representations or not. The instruction for those who were given the direction to integrate the representations consisted of three parts. First of all, the participants were introduced to the concept of "What are multiple representations?" Then they were given a short paragraph explaining the structure of human heart and a picture demonstrating the different parts of human heart in order to help them understand the basic process of integrating text and diagram. Lastly, the instruction explained the possible benefits of integrating multiple representations and explicitly set goals for the participants to integrate the representations. Participants needed to inspect the diagrams and think about how they were related to the information in the texts. Participants who were given instructions without direction to integrate were simply told to study the instructional material. For the participants in the color code condition, the instruction also told them that the corresponding highlighted labels might provide a cue to locate the related elements. (Appendix D)

Instructional Materials

In this study, the effect of color coding on learning outcomes was investigated in a computer-based learning environment. All participants were asked to read biology learning material on the topic of skeletal muscles. The learning material consisted of two different representations: texts and diagrams. Text and diagram information was coherently inter-related. The learning material described the structures of muscle cells and explained the mechanism of muscle contraction and relaxation. After a short introduction of the learning content, the participants were given four chapters in a fixed sequence.

Two versions of the instructional material were administrated depending on the condition. Participants assigned to the condition receiving color coded received a version of the learning material that had corresponding elements of texts and diagrams highlighted in the same color. For example, a learner would see the word "sarcomere" in the text was highlighted in green as was the word "sarcomere" when presented in the diagram. Participants assigned to the condition that did not receive color coded text-to-diagram linking were given a version of the materials where all text was presented in black font. (Appendix E)

Measures

Demographics

Each participant completed a demographics questionnaire on which they report gender, ethnicity, year in school, major, and GPA. (Appendix A)

Pretest

The pretest for prior knowledge consisted of 20 multiple-choice questions about general biology knowledge and 5 multiple-choice questions about the content domain. This pretest was intended to assess learners' general prior knowledge about biology generally as well as the content specific knowledge. This test had a medium level of difficulty ($p = 0.56$). (Appendix B)

Cognitive Load

After each participant completed the learning section, they were asked to rate the subjective cognitive load associated with learning the instructional materials. The ratings were collected on a seven-point scale ranging from 1 (extremely easy) to 7 (extremely difficult) with participants self reporting on how easy or difficult the instructional material was to understand (Pass, 1992).

This rating scale is used to determine, the perceived intensity of mental effort. The intensity of effort is considered to be an index of cognitive load. The scale is a modified version of Bratfisch, Borg, and Dornic's scale (1972) for measuring perceived task difficulty. In their study a Spearman rank order correlation of 0.9 was obtained between objective and subjective task difficulty.

Post-tests

Learning outcome was assessed with a 36-item post-test independent from the pretest including tasks for factual recall and knowledge transfer. The post-test contained 36 multiple-choice items (maximum score of 39 points) with four answers possibilities, divided into three types of items: 13 items on text-only items, 8 items (11points) on diagram-only items, and 15 items on text-diagram items. This post-test had an overall reliability of .776. Six items were removed from original posttest due to their poor reliability (Item-total correlation <.1). The text-only items and the diagram-only items only contained texts and diagrams respectively, whereas the text-diagram items contained both text and diagram in each question. The text-diagram questions could only be answered if learners had integrated information from both text and diagrams.

Each type of items consisted of two forms of tasks: factual recall tasks and knowledge transfer tasks. For the factual recall tasks, the learners were required to recognize terms and statements that were explicitly stated in the texts as well as in the diagrams. Knowledge transfer tasks were measured by questions that required learners to apply inferred concepts to situations not directly mentioned but could be derived from the learning material.

The purpose of this post-test was to assess the degree to which participants have obtained the comprehension of the single representations (text only and diagram only) and of integrating the text with the diagrams. (Appendix C)

Procedures

The study was conducted as a one-and-half-hour session for each student. All participants were given instructions respective to their condition, after that, participants responded to a pretest for prior knowledge by means of a 20-item multiple-choice test. Participants moved to the learning phrase after the pretest was completed.

All tests and instructional materials were presented in a computer-based manner. The learning phase started individually and the presentation of each screen page was learner paced. Depending on condition assignment, learners read the materials in which diagrams and texts were either color coded or not color coded. After finishing the learning phase, the multiple-choice post-test were given to each learner to assess factual recall and knowledge transfer of the texts and of the diagrams.

Chapter 3

Results

Prior Knowledge

The overall mean score of pretest was M=11.23 (*SD*=2.41). The four experimental groups did not differ with respect to their prior knowledge: $F(3,114)= .520$, $p < .05$. The average GPA of all the participants was M=3.35 (*SD*=.38).

Self-rated Cognitive Load

The participants were asked to rate their cognitive load using a seven-point scale ranging from 1 (extremely easy) to 7 (extremely difficult). This was designed to measure participants' cognitive load when they were studying the learning material.

The average cognitive load was M= 5.40 (*SD*=1.07). An ANOVA showed no main effect for either color code: $F(1,109) = .971$, $p > .05$, $\eta^2 = .009$, or instruction, $F(1,109) = .148$, $p > .05$, $\eta^2 = .001$, nor was there an interaction, $F(1,109) = 1.012$, $p > .05$, $\eta^2 = .009$. The participants from color coding condition displayed a lower cognitive load than participants from no-color-coding condition, but the difference was not significant (Table 1).

Table 1. *Means and standard deviations across conditions*

		Color Code (N=60)	No Color Code (N=58)	Instruction (N=55)	No Instruction (N=63)
Cognitive load	*M*	5.30	5.50	5.36	5.44
	SD	1.09	1.05	1.18	.99
Text	*M*	7.49	6.91	7.33	7.06
	SD	2.35	2.48	2.55	2.31
Diagram	*M*	5.95	5.09	5.63	5.41
	SD	2.42	2.33	2.48	2.53
Text-Diagram	*M*	6.83	6.34	7.10	6.09
	SD	2.54	2.85	2.70	2.62

Learning outcomes

The learning outcomes were assessed by the scores on three types of multiple-choice questions: text-only, diagram-only, and text-diagram. The average score of the remaining post-test items was 19.26 (*SD*= 6.22). Participants in the condition with both color coded material and integration instructions scored higher for all three types of questions than any other group (Table. 2)

Text-only items

The text-only questions were designed to assess how well participants learned from the text in the learning material. This part consisted of 13 multiple-choice items, 8 for factual recall and 5 for knowledge transfer, that were worth one point each. The average score of text-only items was 7.19 (*SD*= 2.42), and had a reliability of .529. It was hypothesized that the condition manipulations would have no effects on participants' scores for text-only questions. To test this prediction, the results were analyzed by a 2x2 ANOVA with color coding and instruction as independent variables. This variable met the assumption of homogeneity, $F(3, 114)= 1.074$, $p > .05$. There were no main effects for either color coding, $F(1, 114) = 1.662$, $p > .05$, $\eta^2 = .014$, or instruction, $F(1, 114) = .382$, $p > .05$, $\eta^2 = 003$, nor was there an interaction, $F(1, 114) = 1.036$, $p > .05$, $\eta^2 = 009$. Means and standard deviations for this variable are given for each condition in Table 2.

Diagram-only items

The post-test scores for diagram-only questions intended to measure the participants' knowledge acquisition from the diagrams in the learning material. The diagram-only items contained 8 multiple-choice items (11 points), 3 (6 points) for factual recall and 5 for knowledge transfer, that were worth one point each, except there was one “label” question worth four points. The average score was 5.52 (*SD*=2.14). This variable met the assumption of homogeneity, $F(3, 114)= 1.141$, $p > .05$. A 2x2 ANOVA with color coding as well as instruction as independent variables was conducted on the post-test score of diagram-only items. This analysis revealed a significant main effect for color coding, *F*(1,

114) = 3.834, $p = .05$, $\eta^2 = .033$, indicating that participants who read the learning material with color coding scored significantly higher in diagram-only items than participants who read the learning material without color coding.

There was no significant main effect on the instruction (with/without) on the students performance for diagram-only items, $F(1, 114) = .237$, $p > .05$, $\eta^2 = .002$, nor a significant interaction between these two independent variables, $F(1, 114) = .157$, $p > .05$, $\eta^2 = .001$. Means and standard deviations for this variable are given for each condition in Table 2.

Text-diagram items

The average score for text-diagram items was 6.56 (SD=2.69) out of 15 points. A 2x2 ANOVA with color coding as well as instruction as independent variables was performed on the post-test score of text-diagram items. This variable met the assumption of homogeneity, $F(3, 114)= .402$, $p > .05$. Means and standard deviations for this variable are given for each condition in Table 2. This analysis showed a significant main effect for instruction on the post-test score of text-diagram items, $F(1, 114) = 4.205$, $p < .05$, $\eta^2 = .036$. The results showed that participants who were given instructions for integration scored significantly higher than participants who were not given instructions. In addition, the ANOVA analysis failed to show a main effect of color coding, $F(1, 114) = .998$, $p > .05$, $\eta^2 = .009$, or a significant interaction between color coding and instruction, $F(1, 114) = .093$, $p > .05$, $\eta^2 = .000$.

Table 2. *Means and standard deviations across four groups.*

		Color code		Without color code	
		Instruction	Without instruction	Instruction	Without instruction
Text-only	*M*	7.85	7.12	6.82	7.00
	SD	2.25	2.41	2.75	2.24
	n	27	33	28	30
Diagram-only	*M*	6.15	5.76	5.11	5.07
	SD	2.35	2.50	2.54	2.16
	n	27	33	28	30
Text-Diagram	*M*	7.37	6.30	6.82	5.87
	SD	2.48	2.52	2.92	2.75
	n	27	33	28	30
Total	*M*	21.37	19.18	18.75	17.93
	SD	5.83	5.98	6.88	5.98
	n	27	33	28	30

Chapter 4

Discussion

Multimedia learning environments usually require learners to integrate information from different representations to construct a coherent mental representation. The integration process could be highly demanding, especially for learners with lower level of prior knowledge. Two different approaches were examined in facilitating integration. First, in order to avoid the extensive search and match behavior in the integration process, the corresponding elements in different representations were signaled and highlighted. Second, the learners were explicitly instructed to integrate information from different representations to acquire a coherent mental representation. This study aimed at investigating the effects of both manipulations given alone or in combination on different types of learning outcomes as well as cognitive load.

The use of color coding technique was expected to reduce extraneous cognitive load and thus enhance learning. The participants in color code condition reported lower cognitive load than participants in no-color-code condition, but the difference was not significant. This may be due to the fact that the learning material was complex and mentally demanding, especially for learners with a lower level of prior knowledge. With respect to the amount of intrinsic cognitive load required to complete the learning task, learners might reach the ceiling of cognitive resources and thus reported high cognitive load. In other words, the learning material may require too much cognitive resources and therefore failed to display a variability of subjective cognitive load among individual learners. Additionally, in order to better differentiate three types of cognitive load (i.e. extraneous, intrinsic, and germane load), different assessments should be developed to measure learners' cognitive load. In other words, if the learning material itself is already highly complex and thus cognitively demanding, then it makes it more difficult for learners to actively use the provided help. Therefore, it would be interesting to investigate these two types of support on less complex learning material and take the intrinsic cognitive load into account.

The results of learning outcomes revealed that participants in the color coding condition scored higher than participants who did not receive color coded information for the diagram-only items, not for the text-diagram items, which was not consistent with the hypothesis. The possible reason might be the design of color coding did guide participants' attention to the diagram to facilitate their comprehension within the diagram representation. However, the better recall and deeper understanding of a single representation could not guarantee that participants have paid attention to the relationship between text and diagrams during the learning process. It should be noted that the attention to different instructional representations is essentially a preliminary activity to integration. Participants might still not be aware that they should relate the information from text and diagrams and construct a coherent mental model. Participants with color coded material might be simply directed to diagrams and spend more time studying diagrams than did participants in the control condition, therefore outperformed in the diagram-only items.

In contrast, participants in the condition that received direction to integrate text and diagrams scored significantly higher than did participants in the control condition on text-diagram items, but not on diagram-only items. It provided evidence that the general instruction of integration did help to improve learners' awareness of integration when learning from multiple representations. However, it appeared that the effort spent on relating different representations did not lead to better learning outcomes for any individual representation. It is possible that participants who actively engaged in the integration of multiple representations gained a deeper understanding of the learning material as a whole. In other words, they might have better understanding of how the muscle contracting system works as a whole. However, the construction of a global coherent mental model might not be reflected by text-only or diagram-only items because these two types of items focused more on the memorization and understanding of single piece of the domain knowledge, rather than understanding it as a whole system.

With respect to the combination of color code and instruction, it was hypothesized that the participants who received both treatments would perform better in diagram-only and text-diagram items. This group in fact reached the highest learning scores for all three types of post-test items and lowest rates for cognitive load, but the findings were not significant.

Whether learners really integrate when processing the multiple representations and in which way they integrated cannot be answered by this study. It would be helpful to collect process data, for example think-aloud or eye movement during the learning process. Future research should also take into account learner characteristics, such as prior knowledge, for learning outcomes and cognitive load.

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Appendix A

Demographics

1. What is your gender?

A. Male
B. Female

2. What is your current academic status?

A. Undergradute
B. Graduate
C. Other

3. What is your enrollment status?

A. Full time
B. Part time

4. What year of school are you in?

A. Freshmen
B. Sophomore
C. Junior
D. Senior
E. Graduate
F. Other

5. What is your GPA? _______

6. What is your age?

A. 18-22
B. 23-30
C. 31+

7. What is your major? ________

Appendix B

Pretest

1. The part of the tooth which contains the hardest substance in the body is the____________.

A. Root

B. Dentine

C. Cement

D. Enamel

Answer: D

2. The chief value of perspiration is that it ___________

A. Eliminates body odors

B. Opens the pores

C. Reduces weight

D. Regulates body temperature

Answer: D

3. Endocrine glands produce________

A. Enzyme

B. Endoplasm

C. Hormones

D. Serums

Answer: C

4. The hollow interior of the long bones is filled with__________

A. Marrow

B. Minerals

C. Red and white corpuscles

D. Haversian canals

Answer: A

5. The carbon dioxide-oxygen exchange with the atmosphere occurs in the_____

A. Nose

B. Trachea

C. Lungs

D. Bronchi

Answer: C

6. Blood is oxygenated in the capillaries of the__________

A. Air sacs

B. Heart

C. Muscle

D. Liver

Answer: A

7. The part of the brain that controls respiration is the___________

A. Medulla

B. Cerebellum

C. Cerebrum

D. Spinal cord

Answer: A

8. A defense of the body against bacteria is ___________

A. Hemoglobin

B. Phagocytes

C. Red blood cells

D. Blood platelets

Answer: B

9. The disease hemophilia is associated with _________

A. The bone structure

B. Blood clotting

C. The structure of nervous tissue

D. The formation of red corpuscles

Answer: B

10. The liquid that bathes every cell and acts as a medium of exchange is_______

A. Cell sap

B. Fibrinogen

C. Lymph

D. Fibrin

Answer: C

11. The concentration of sodium and potassium in the blood is controlled by________

A. Adrenin

B. Cortin

C. Insulin

D. Secretin

Answer: D

12. Diabetes is caused by the improper functioning of the_________

A. Parathyroids

B. Thyroids

C. Pancreas

D. Adrenals

Answer: C

13. Growth and repair of body tissue involves__________

A. Protein

B. Fats

C. Starch

D. Sugar

Answer: A

14. The portion of the heart which divides it longitudinally into 2 halves is called the_________

A. Myocardium

B. Tendons

C. Pericardium

D. Septum

Answer: D

15. A blood vessel which carries deoxygenated blood is the________

A. Aorta

B. Pulmonary Artery

C. Hepatic Artery

D. Pulmonary Vein

Answer: B

16. The backward flow of blood in the veins is prevented by__________

A. Muscles

B. Valves

C. The heart beat

D. Lymphatics

Answer: B

17. ________ muscles control voluntary movement

A. Smooth

B. Unstriated

C. Skeletal

D. Cardiac

Answer: C

18. When a person wants to move a part of his body, a signal is sent from the brain to the muscle through __________

A. Motor neurons

B. The myelin sheath

C. Sensory neurons

D. Temporal lobe

Answer: A

19. _______ is a neurotransmitter that is involved in the translation of signals from the nervous system to muscle cells

A. Probiol

B. Acetylcholine

C. Epinephrine

D. Sodium

Answer: B

20. ________ is a nucleotide that provides the energy for most of the energy-consuming activities of the cell

A. ADP

B. Peptide

C. Phosphate

D. ATP

Answer: D

Appendix C

Posttest

Self-rated Cognitive Load

Please indicate how easy or difficult the material you just went through was to understand (i.e., did it take a lot of mental effort)? Please circle a number from 1-7. 1 being the easiest and 7 being the hardest.

Text-only

Factual Recall

1. During cross-bridge formation ______________

A. thick and thin filaments are joined
B. the synaptic vesicles fuse with the membrane of the sarcolemma
C. an action potential travels across the sarcomere
D. the muscle cell relaxes

Answer: A

2. Thick filaments are mostly made of ____________

A. calcium
B. acetylcholine (ACh)
C. myosin
D. sarcomeres

Answer: C

3. Action potentials travel through the _________ to reach deep inside the muscle cell

A. sarcolemma
B. myofibrils
C. t tubules
D. thin filaments

Answer: C

4. Muscle fibers are surrounded by ______________

A. myofilaments

B. sarcolemma
C. synaptic vesicles
D. thick filaments

Answer: B

5. When the brain sends a signal to relax, _______________

A. calcium ions are released
B. the sarcomeres return to their original length
C. action potentials are sent to the motor neurons
D. t tubules retract

Answer: B

6. Energy needed for muscle contraction is provided by ______

A. ATP
B. ADP
C. ACh
D. AChE

Answer: A

7. During a power stroke, _____________

A. the muscle is shortened
B. AChE dissolves acetylcholine (ACh)
C. a cross-bridge is broke
D. pumps pull calcium (Ca+) ions out of the sarcoplasm

Answer: A

8. To reach the muscle cell membrane, acetylcholine (Ach) passes through the _____________

A. motor neuron
B. synaptic cleft
C. thin filament
D. troponin complex

Answer: B

Knowledge Transfer

9. The list below contains a sequence of processes. From the options provided, select the process that belongs in the missing slot. 1.Energy is released when ATP is transformed to ADP 2.Myosin head bends back 3.__________________________ 4.Myosin head bends and pulls thin filament

A. Calcium is released from active sites
B. Myosin head attaches to active sites on G actin
C. Troponin is released from thin filament
D. Calcium ions separate from troponin

Answer: B

10. Imagine that a person lacks calcium ions. Which of the following would that deficiency directly affect?

A. the synaptic vesicles could not fuse with the muscle cell membrane
B. receptors on the sarcolemma would not change shape
C. ACh would be blocked by AChE
D. Active sites on thin filaments would not be uncovered

Answer: D

11. If the synaptic vesicle could not fuse with the cell membrane,

A. a contracted muscle cell could not relax
B. t tubules would be blocked
C. the action potential would not be passed down the muscle fiber
D. thick filaments could not detach from thin filaments

Answer: C

12. During muscle relaxation, which process immediately follows the removal of calcium ions from the sarcoplasm?

A. active sites are covered by tropomyosin
B. Actin-myosin cross-bridges are formed between thin and thick filaments
C. AChE dissolves ACh
D. Synaptic vesicles separate from the muscle cell membrane

Answer: A

13 Which of the following statements accurately describes the structures of a muscle?
.

A. The structures of a muscle fiber are encased within the sarcolemma.

B. Motor neurons fuse with t tubules.
C. Synaptic vesicles are contained in the sarcomere.
D. The sarcoplasmic reticulum lies between the synaptic knob and the motor end plate.

Answer: A

14. A person who has been paralyzed is unable to move muscles because ___________________ .

A. there can be no action potential
B. the neuromuscular junction is damaged
C. Calcium ions (Ca+) can no longer travel through the synaptic knob
D. the person lacks ACh

Answer: A

15. If myosin heads were missing from muscle fibers, which process would be impossible?

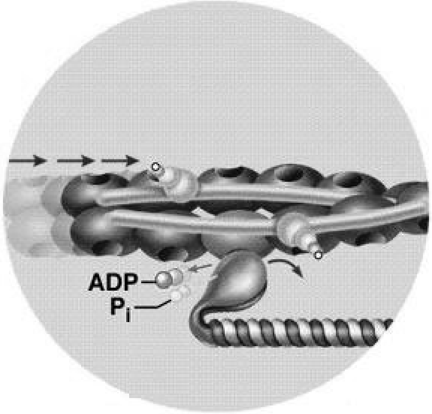
A. Action potential
B. Synaptic fusion
C. Cross-bridge formation
D. End plate potential

Answer: C

Text-Diagram

Factual Recall

1.

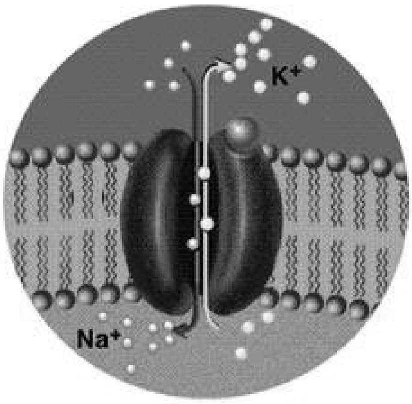


Look at the diagram below/above. From the options below, please select the statement that best describes what is depicted in this diagram.

A. calcium ions dissociate from troponin
B. the ADP and Pi bind to the myosin head
C. the myosin head pulls the thin filament along the thick filament
D. the active sites on G actin are covered by tropomyosin

Answer: C

2.



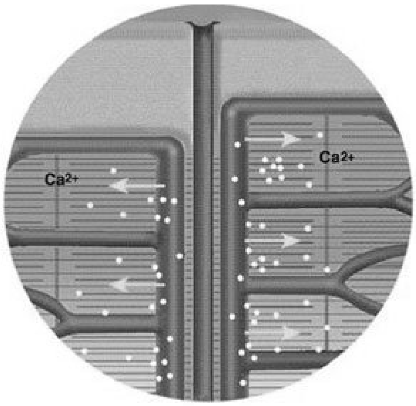
In the diagram above, charged particles are flowing in and out of the muscle cell, creating an electrical charge called________.

A. Sarcoplasm
B. End Plate Potential
C. Calcium Ions
D. Sarcolemma

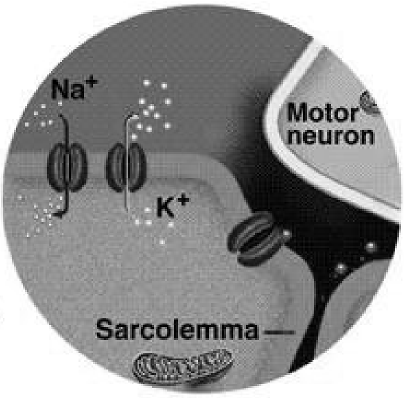
Answer: B

3. Which diagram depicts the diffusion of charged particles and depolarization of the sarcolemma?

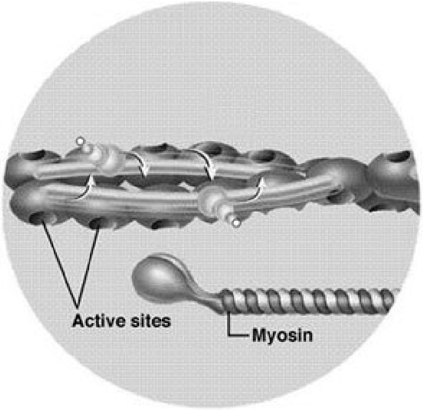
A.



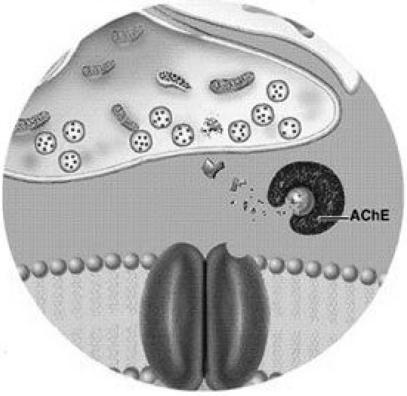
B.



C.

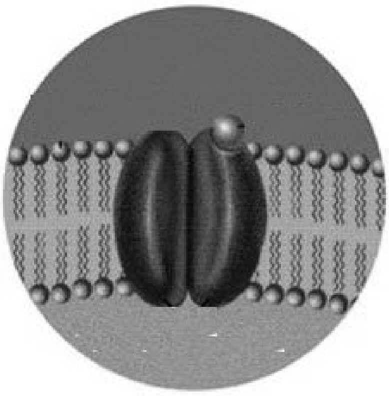


D.



Answer: B

4. What is happening in the photo below:



A. Ach is binding to the receptor
B. Action potentials arrive at the synaptic knob
C. Calcium ions diffusing at the synaptic knob
D. End Plate Potential is reached

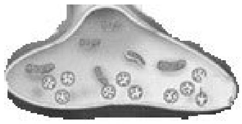
Answer: A

5. From the options below, select the diagram of a thin filament.

A.

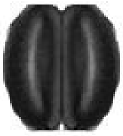
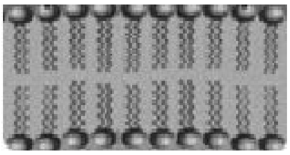
B.

C. 

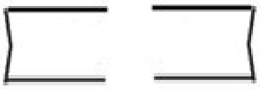
D. 

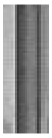
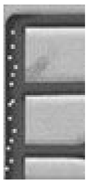
Answer: B

6. From the sets of diagrams below, select the two structures that are directly involved in creating the end plate potential.

A.  and 

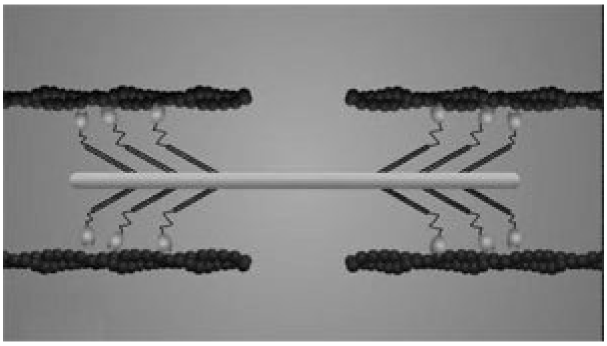
B.  and 

C.  and 

D.  and 

Answer: A

7. The diagram below shows the _______________

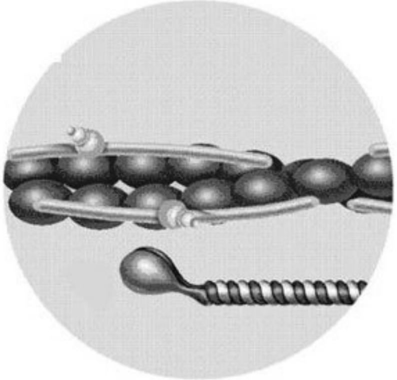


A. fusion of synaptic vesicles with the sarcolemma
B. muscle fibers getting shorter
C. the thick filament in an inactive state
D. muscle fibers relaxing

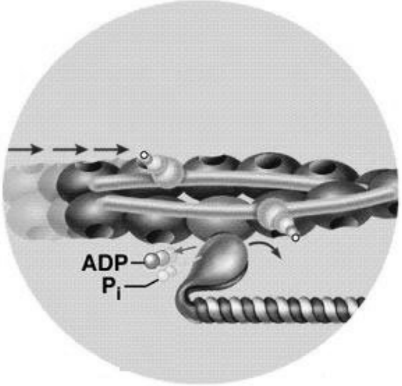
Answer: B

8. When calcium is transported out of the sarcoplasm and back into the sarcoplasmic reticulum, the troponin changes back to its original shape. Which of the following diagrams illustrates this original shape of thick and thin filaments?

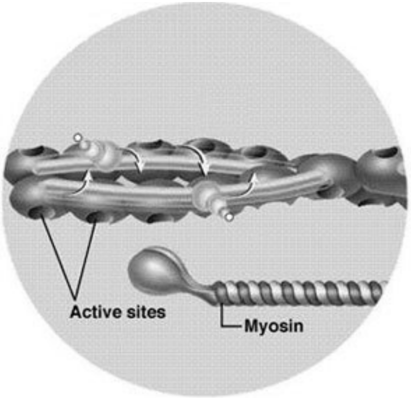
A.



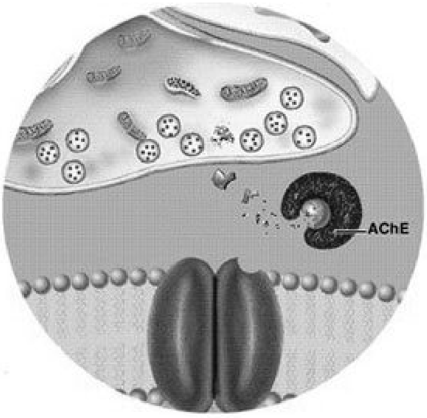
B.



C.



D.

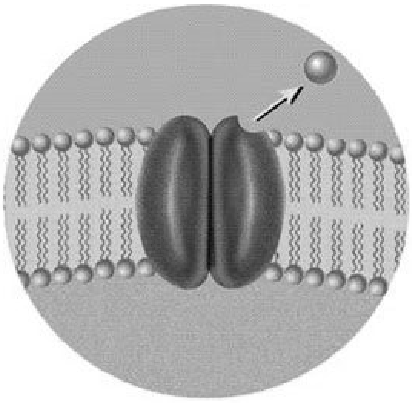


Answer: A

Knowledge Transfer

9. Please select the right description according to the diagram below

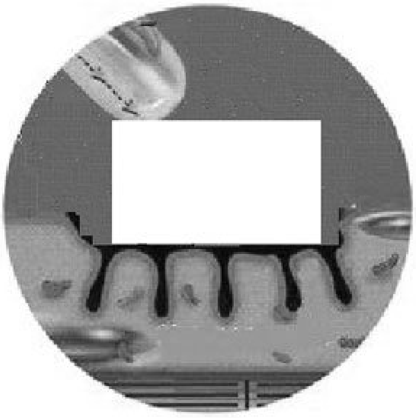
.



- A. The muscle cell is relaxing
- B. The muscle cell is shortening
- C. This is the first stage of the power stroke
- D. In the next step of this process, the released calcium ion will be broken down by AchE

Answer: A

10. Which structure is missing from the diagram below?

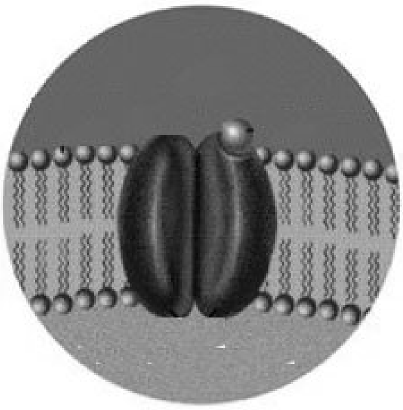


- A. Sarcolemma
- B. T tubules
- C. Synaptic knob
- D. Acetylcholine (ACh)

Answer: C

11. The diagram below depicts one step in the sequence of processes that leads to muscle contraction. From the list below, select the statement that explains which

process immediately follows this step during muscle contraction.

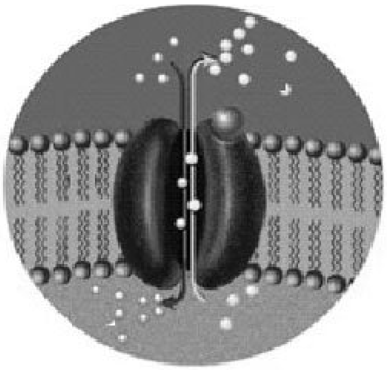


A. Calcium (Ca+) ions bind to troponin in the sarcolemma
B. Potassium (K+) and sodium (Na+) ions are released
C. Acetylcholine is dissolved by AChE
D. Synaptic vesicles release acetylcholine (ACh)

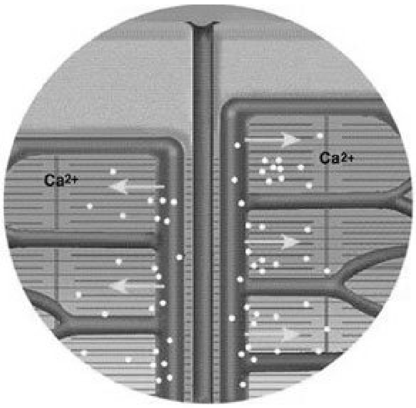
Answer: B

12. Select the diagram that accurately depicts the state of the sarcolemma during muscle contraction

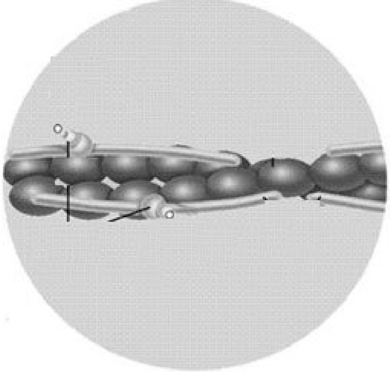
A.



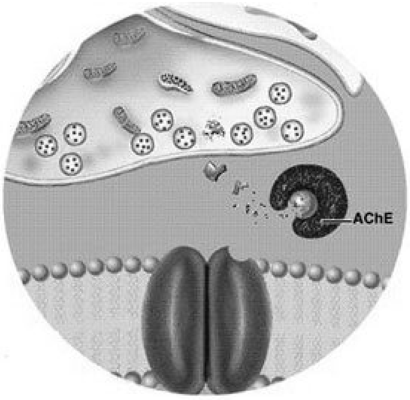
B.



C.

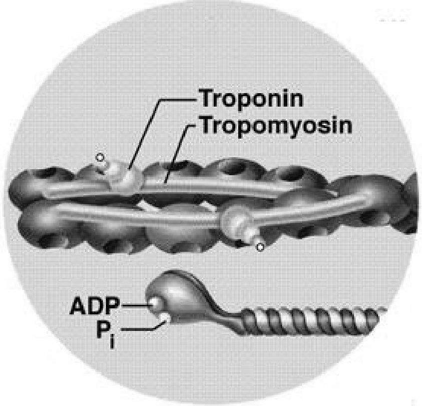


D.



Answer: A

13. Select the label that accurately matches what is depicted in the diagram below



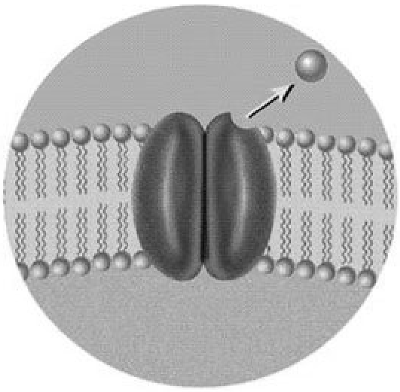
A. Muscle contraction
B. Action potential
C. End plate potential
D. Muscle relaxation

Answer: A

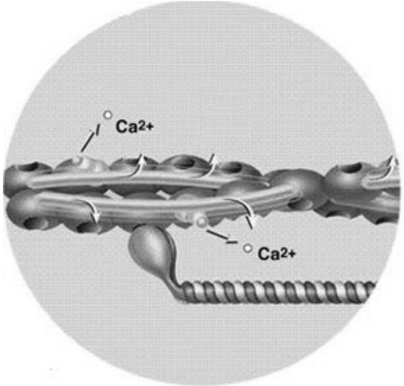
14. Imagine that a person is lifting a heavy box. Select the diagram below that

accurately depicts the muscle state as the person pulls the box toward them.

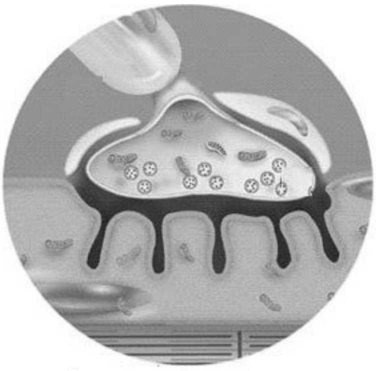
A.



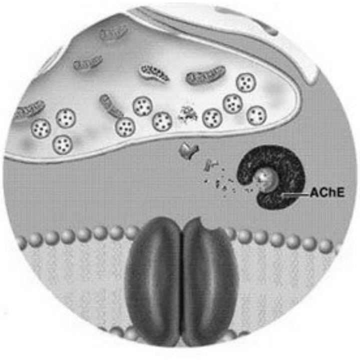
B.



C.

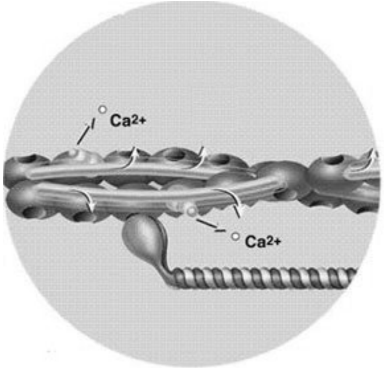


D.



Answer: C

15 Examine the diagram below and select the statement which accurately describes
. what will happen next.

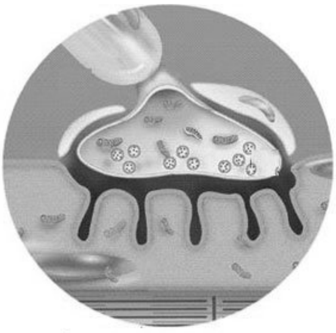


A. When the calcium (Ca+) is removed, troponin changes to its original state and drags tropomyosin back to cover the active sites
B. When the calcium (Ca+) is removed, the active sites are uncovered and a power stroke occurs
C. Calcium is replaced by sodium (K+) and an action potential spreads along the thin filament
D. The muscle cell contracts

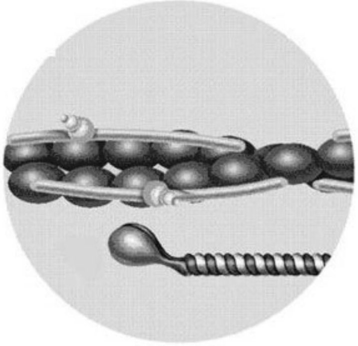
Answer: A

16. Which of the following diagrams accurately depicts the state of the muscle fiber after the calcium pumps have closed?

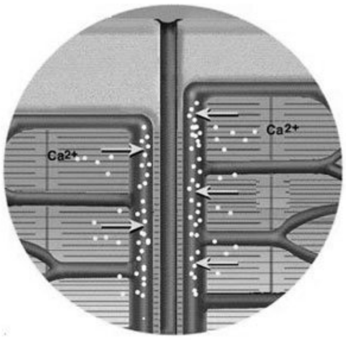
A.



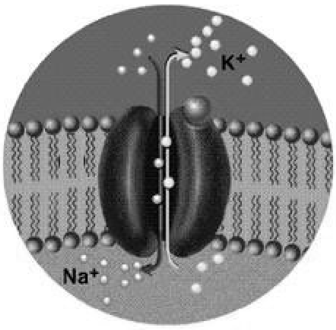
B.



C.



D.

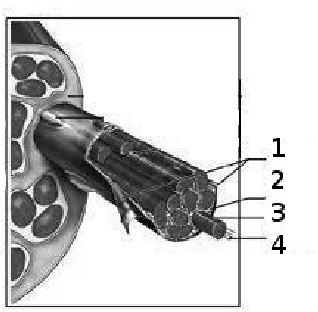


Answer: B

Diagram-only

Factual Recall

1. Please place the number of the structures of a muscle fiber in order according to the number on the image:

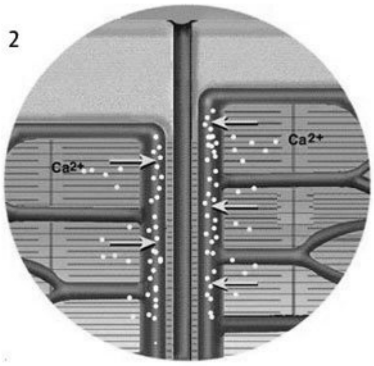


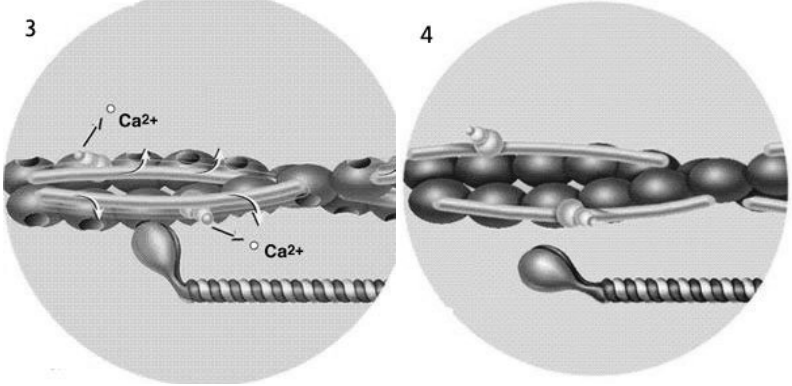
A. myofibrils
B. myofilaments
C. sarcolemma
D. sarcoplasm

Answer: A:3, B:4, C:1, D:2

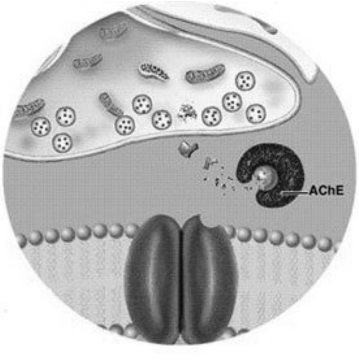
2. The diagrams below show an ordered sequence of actions within muscles. The first diagram is missing. From the options below, please select the image that best depicts the first action in this sequence

1

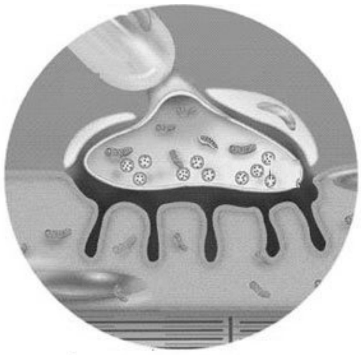




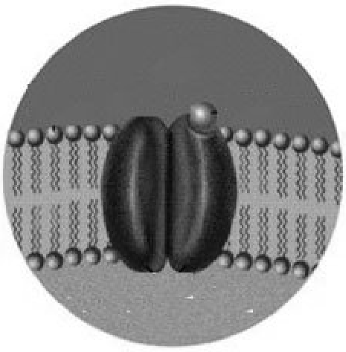
A.



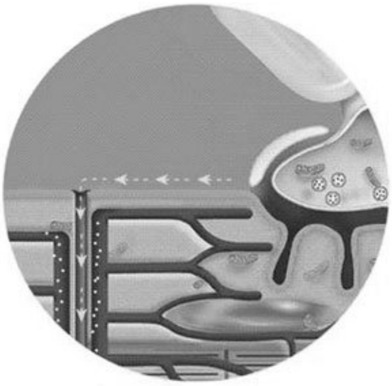
B.



C.

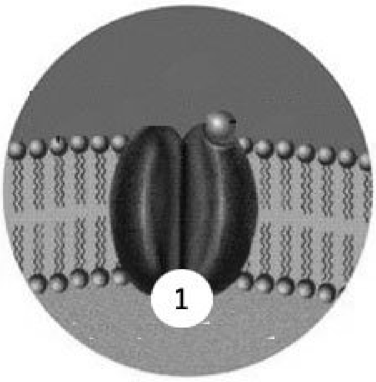


D.



Answer: A

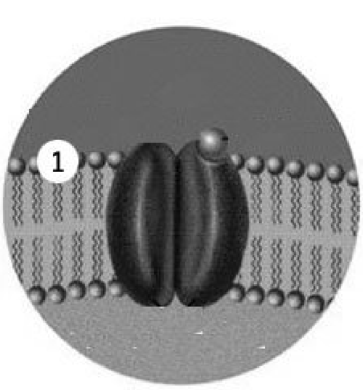
3. Please choose the correct label for number 1



A. Sarcolemma
B. ACh receptor
C. Sarcoplasm
D. troponin

Answer: B

4.



Please choose the correct label for number 1

A. Sarcolemma

B. acetylcholine
C. troponin
D. end plate potential

Answer: A

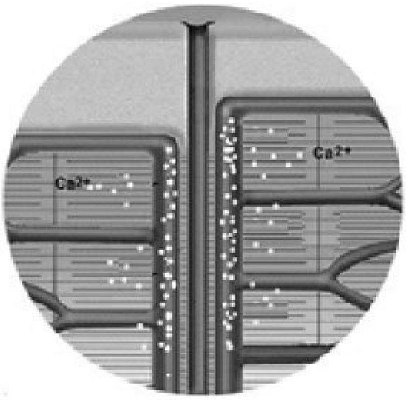
Knowledge Transfer

5 What is wrong with the think filament diagram below?

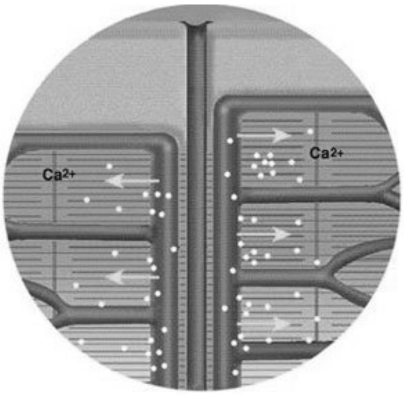
A. thick filaments are made of only a single strand rather than the multiple bands shown here
B. myosin heads are missing
C. thin filaments should be added to this diagram to show how thin and thick filaments are intertwined
D. the receptor sites are missing

Answer: B

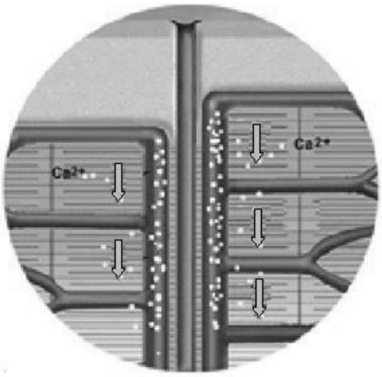
6. The diagram below depicts the movement of Calcium ions (Ca+) during relaxation. This diagram does not include any arrows to show the direction of Ca+ flow. From the list below, select the diagram in which directional arrows are correctly placed.



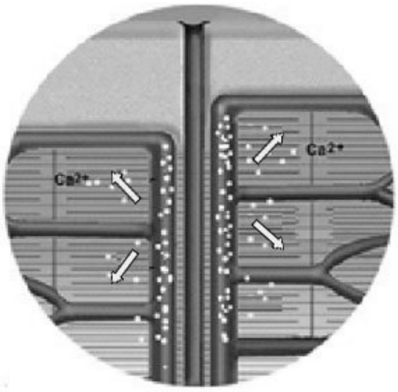
A.



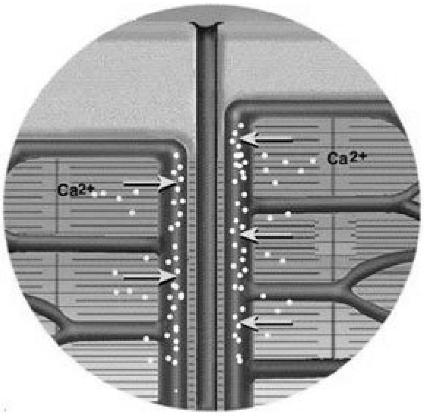
B.



C.

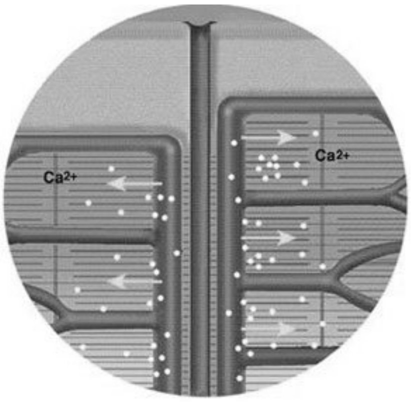


D.



Answer: D

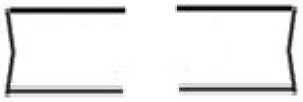
7. Use the following picture to help answer the question. What is causing these Ca2+ channels to be diffused into the sarcoplasm?



A. Action potentials
B. Synaptic Vesicles
C. Thin Filament
D. Thick Filament

Answer: A

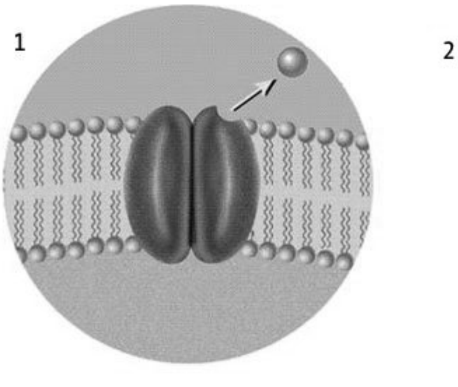
8. Which structure belongs inside the circled area of the diagram below?



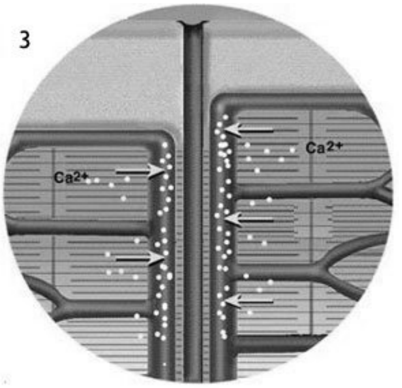
A. The sarcomere
B. A thick filament
C. T tubules
D. A thin filament

Answer: B

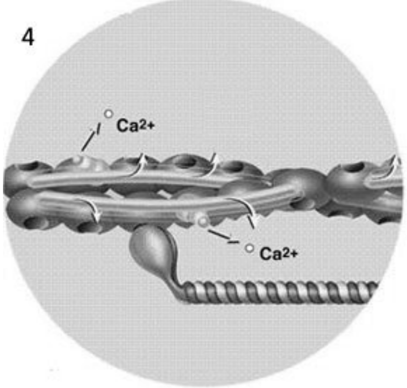
9. In the sequence below, one diagram is missing. From the provided list, select the diagram that should be inserted into the missing slot.



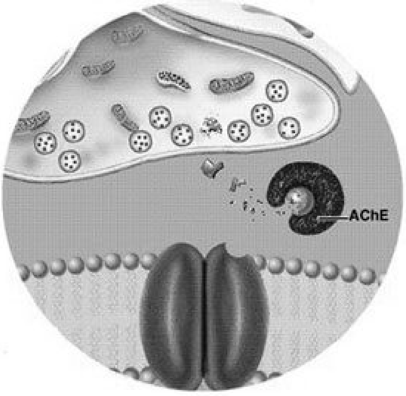
3



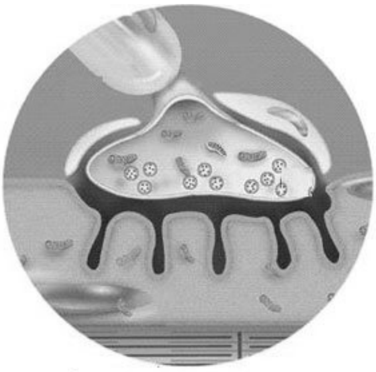
4



A.



B.



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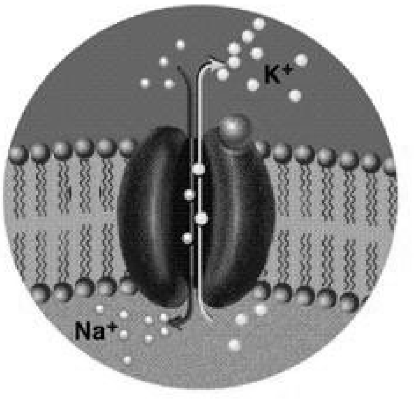
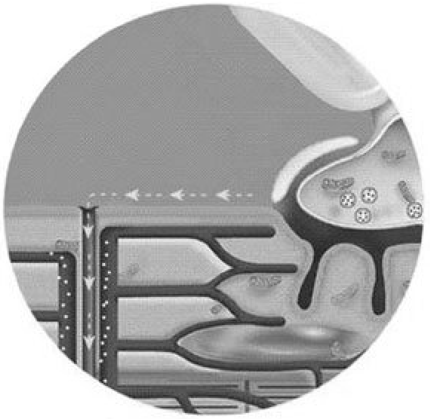


D.



Answer: A

10. The structure shown in Figure 1 is located within the structures shown in Figure 2. Each diagram in the list below has a circled area. Select the numbered location that accurately circles the location where Figure 1 could be inserted.

Figure 1

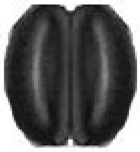
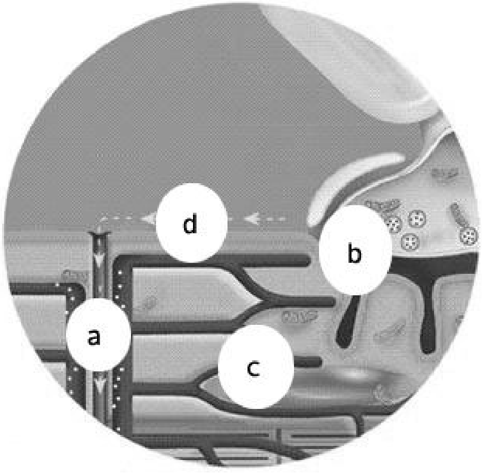


Figure 2



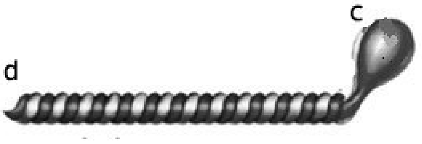
A. area along t tubles
B. on the edge of the synapse, near where the vesicles would be
C. inside the muscle fiber, not only tubules of near motor end plate
D. along the edge of the sarcolemma, just below where the arrows are located

Answer: D

11. Figure 1 shows the structures of a muscle fiber. From the options, select the letter

that correctly indicates the location where calcium (Ca2+) can bind.

Figure 1



A. Spot on G actin
B. Spot on Troponin complex
C. On end of myosin head
D. Spot along tail of myosin molecule

Answer: B

Appendix D

Integration Instruction

1. What are multiple representations?

- Learning materials that contain more than one representation.

Example: texts, diagrams, formulas, tables etc.

(Think about your biology text book)

The importance of integrating multiple representations.

Sometimes, these different representations may convey the same information. Other times, different forms of representations may provide different information. In either case, **it's important to study all the representations and to think about how the representations are related to each other, so that you can understand them as a whole.** Even when the representations contain the same information, you will learn more if you study both because they explain the information in different ways.

2. How to integrate multiple representations?

To better integrate different representations, the learning process should include the following steps:

- Read through and **understand the content of each representation** (e.g. both text and diagram)

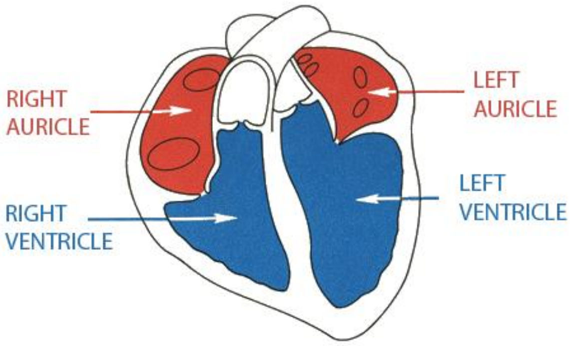
- **Think about the relationship** between different representations

- Try to **connect the information** in the representations to form a complete understanding, which includes information from all representations

To better understand how to integrate, let's look at the following example. Imagine that you are reading a biology text about the human heart. You read the text and also see the diagram. You try to combine the information from the text and the diagram.

Please pay close attention to the underlined sentence and connect it with the diagram.

Example:



Human Heart

Each half of the heart is divided into an upper chamber and a lower chamber. **The upper chambers on each side of the septum are called Auricles; the lower chambers are called Ventricles.** Auricles have thin walls and act as receiving rooms for the blood, while the Ventricles having thicker walls act as pumps moving the blood away from the heart. Although there is no direct communication between the right and left sides, both sides function simultaneously.

During the integration process, your eyes might look back and forth between different representations. You see important concepts in the text and you look at the diagram to locate that concept and study how it is shown there.

For example, in the text, you read that the auricles are in the upper chamber and the ventricles are the lower chamber. You might then look at the diagram and see where these structures are located and what they look like. As you read on, you learn that the ventricles have thicker walls because these act as pumps. You might then look at the diagram and think, “Okay, so the blood comes in through the top and then it is pumped out of the bottom. The ventricles at the bottom are the pumps.”

3. Learning from integration

In this study, we want you to read some biology material about muscles and how they work. These materials include both written words and many diagrams. As you study this material, we want you to inspect the diagrams and think about how they are related to what you are reading about. The corresponding labels might provide a cue for you to locate the related elements.

To make this easier, when you look at the materials, you will find that some of the words have been color coded. That same label is coded in the same color in corresponding diagrams. We have done this so that it is easier for you to see the relationship between what is written and what is shown in the diagrams.

So, **as you read and encounter color coded terms, you can easily locate the corresponding structures in the diagrams.**

Your task:

- Read through the learning material

- Understand as best as you can

- Integrate multiple representations

Appendix E

Instructional Material

Introduction

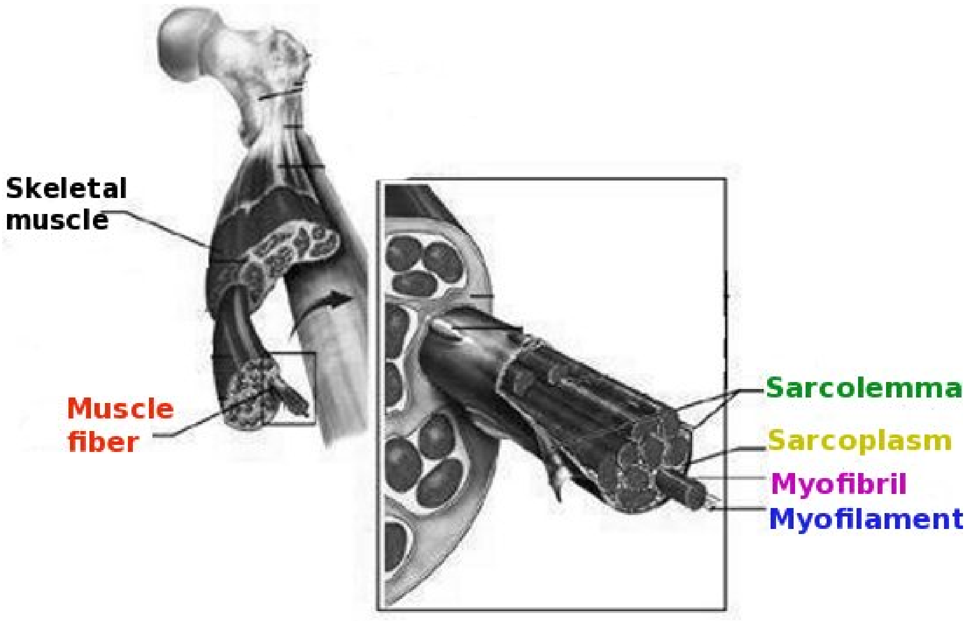
The following instruction begins by giving you a comprehensive overview of muscle structure to help provide you with a general understanding of the parts and how they operate. You will then be presented with the processes of muscle contraction and relaxation. When you have finished this instruction, you should have a basic understand of the anatomy of a muscle and the mechanism of skeletal muscle contraction.

Characteristics of Skeletal Muscle

The functions of muscles inside your body include moving and stabilizing your skeleton. Muscle cells accomplish all of this through a combination of contracting, relaxing, and even stretching. When a muscle cell contracts, it generates a force which pulls or squeezes something. Skeletal muscle contracts to pull a bone. Whole skeletal muscles, such as the bicep or triceps muscles in your arm, become shorter because individual cells within the muscle are contracting (shortening). The individual muscle cells work together to pull on, and move the bone. The signal to contract a muscle originates from the nervous system or the muscle itself.

Muscle cell contraction is coordinated by an electric signal called an action potential. Both muscle cells and nerve cells are capable of generating action potentials on their membranes. Before we can explain how this action potential is generated and affects muscle cells, you must first become familiar with some of the parts of muscle. These parts are identified in the following section.

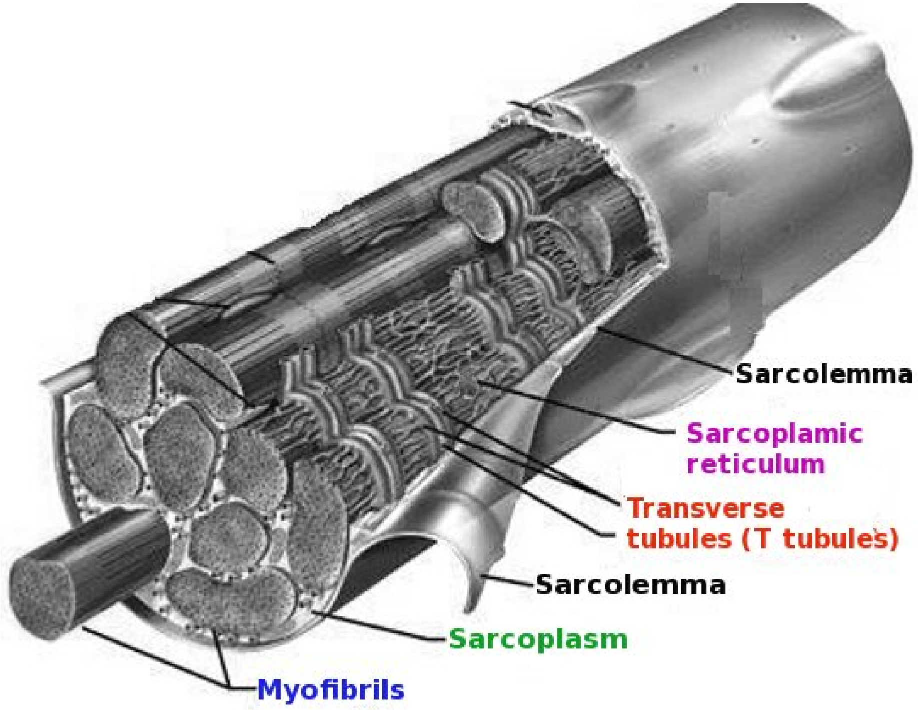
Anatomy of Skeletal Muscle



Individual muscle cells, which can also be called **muscle fibers,** are bundled together to form groups of cells.

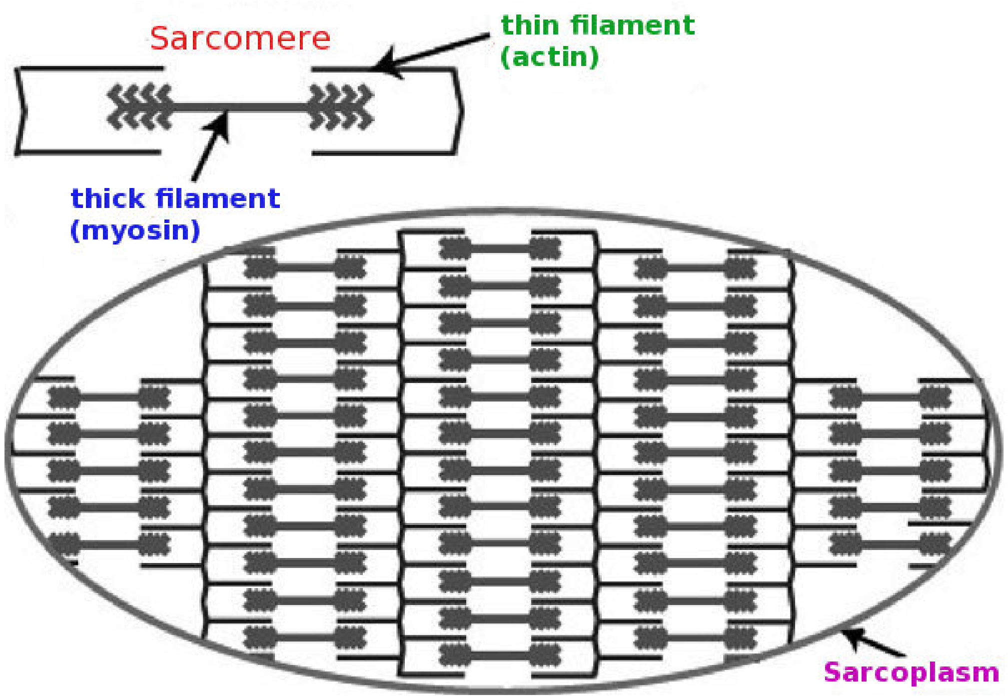
These **muscle fibers** are surrounded by a cell membrane called the **sarcolemma.** Within the sarcolemma is **sarcoplasm,** or the cytoplasm of a muscle cell. The sarcoplasm contains two sets of structures that play important roles in muscle movement. These two are the sarcoplasmic reticulum and sarcomere. The sarcoplasmic reticulum is a complex network of membrane sacs and tubes; sarcomere are made up of bundles of protein called **myofibrils.** These myofibrils are made up of **myofilaments.**

We will be discussing them respectively in the following parts.

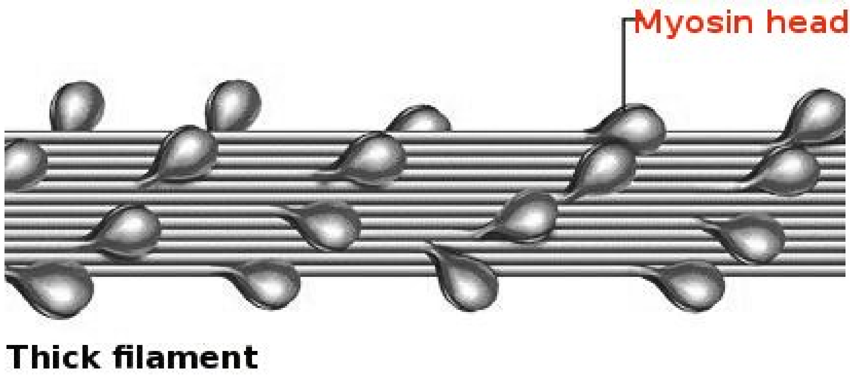


The first important set of structures contained in the **sarcoplasm** is the **sarcoplasmic reticulum**. The **sarcoplasmic reticulum** is a complex network of membrane sacs and tubes (sarcoplasmic = cytoplasm, reticulum=network). The sarcoplasmic reticulum is full of calcium ions. The ends of the **sarcoplasmic reticulum** form large flat sacs called terminal cisternae. The terminal cisternae of the sarcoplasmic reticulum lie against narrow tubes called **transverse tubules (T tubules).** The T tubules travel from the terminal cisternae to the surface of the cell and connect directly to the **sarcolemma** (or cell membrane of the muscle fiber).

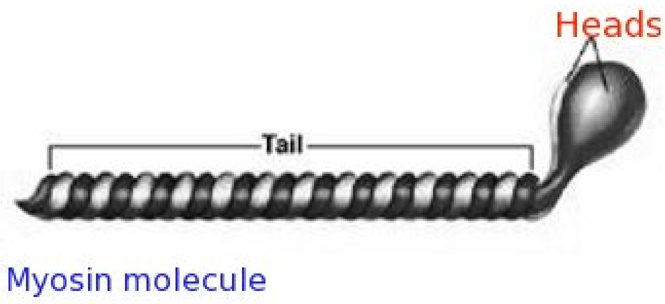
Structure of the Sarcomere

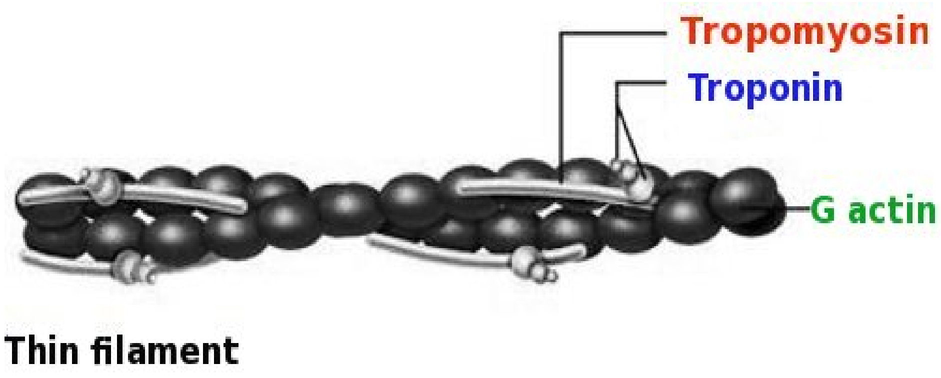


The second important set of structures in the **sarcoplasm** is sarcomere. **Sarcomeres** are the functional units of a muscle cell. Understanding the structure of **sarcomere** is necessary for understanding how muscles contract. **Sarcomere** are made up of bundles of protein called myofibrils. These myofibrils are made up of myofilaments. There are two types of myofilaments that we will be discussing, **thick filaments** and **thin filaments**. In order to keep the muscle cell diagram at the right simple, the sarcoplasmic reticulum was not included. If they had been included, the sarcoplasmic reticulum would lie over and in between the sarcomeres pictured.



The **thick filaments** of the sarcomere are made of many myosin protein molecules bundled together.An individual **myosin molecule** looks a little like a golf club. The **head of the myosin** molecule is hinged and can move back and forth.



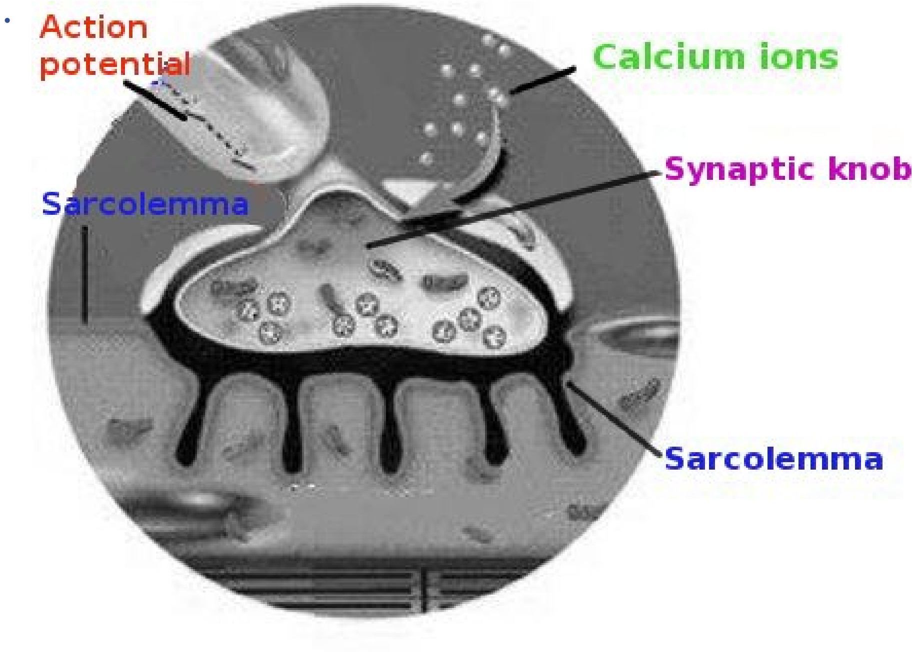


The **thin filaments** are made from different proteins. The long string of bead-like molecules is called F actin. Each individual bead is **G actin.** Each molecule of **G actin** has an active site where the myosin heads can bind during muscle cell contraction. When the muscle is relaxed, the myosin heads of the thick filament cannot bind to the active sites of the thin filament, because long chains of **tropomyosin** cover the active sites. Small proteins called **troponin** are attached along the length of the **tropomyosin** chains of the **thin filament.**

When calcium is present inside the sarcoplasm, the calcium binds to the **troponin** proteins, causing it to change shape. By changing their shape, troponin proteins can pull the **tropomyosin** chains away from the active sites of the **thin filament**. As the **troponin** molecules change shape, they drag the **tropomyosin** chain off of the active sites. Once these sites are uncovered, myosin is able to bind to the active sites on the **G actin**. (Recall that the head of the myosin molecule is hinged and can move back and forth). This causes the sarcomere to become shorter.

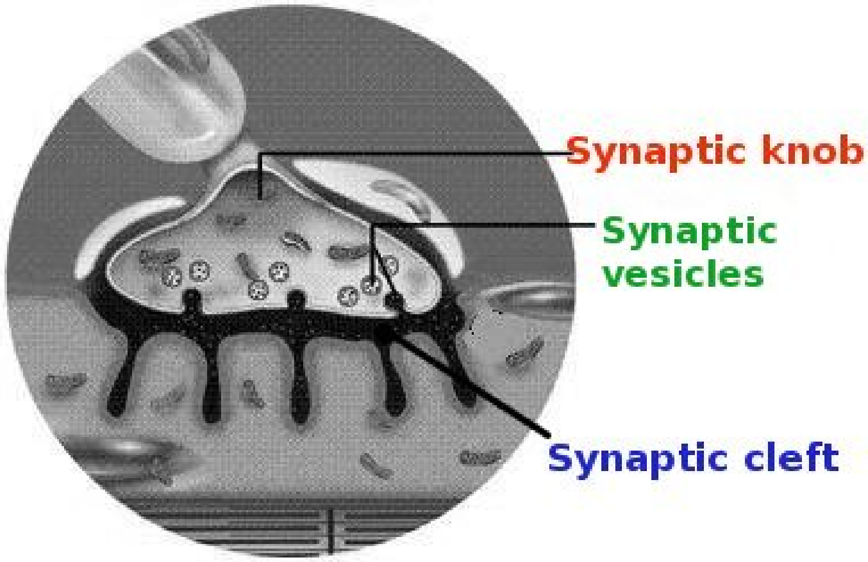
The presence of calcium causes the myofilaments to change shape and triggers a muscle contraction. Before we further looking into these changes, let's look at how the nervous system stimulates a muscle contraction, how this stimulation leads to the release of calcium from the sarcoplasmic reticulum, and the shortening of the sarcomeres.

The Neuromuscular Junction and Excitation-Contraction Coupling

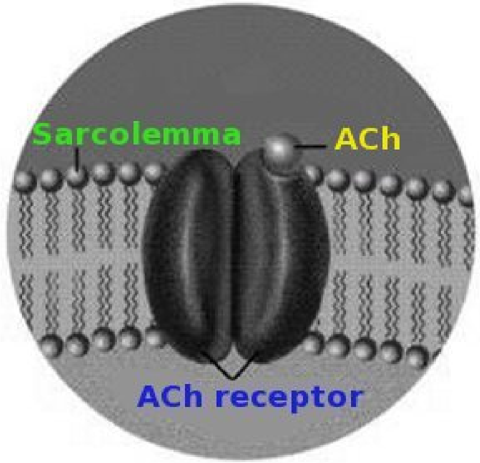


Skeletal muscle is made to contract when neurons from the central nervous system stimulate the muscle cells. Neurons that stimulate muscle cells are called motor neurons. A motor neuron travels from the central nervous system and synapses, or connects with a muscle cell. The synapse between a motor neuron and a muscle cell is called the neuromuscular junction.

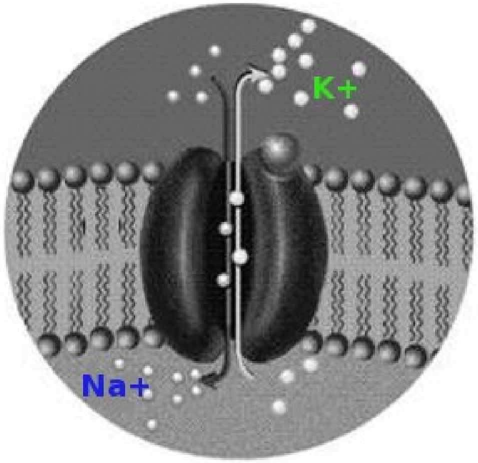
Action potentials, which are electric signals traveling across the membrane of a cell, travel down the axon of the motor neuron and arrive at the **synaptic knob** (axon terminal). The action potential causes **calcium ions** to diffuse into the synaptic knob of the neuron.



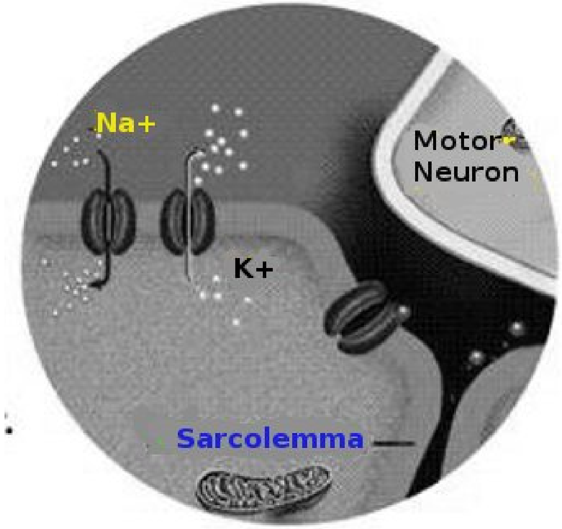
Once inside the neuron, calcium ions attach to proteins found inside the **synaptic knob.** This binding causes the **synaptic knob** to change form from an inactive shape to an active shape. Once activated this protein will move **synaptic vesicles** full of the neurotransmitter acetylcholine (Ach) to the cell membrane. With the help of the proteins, the **synaptic vesicles** will fuse with the cell membrane, and spill the Ach into to a tiny space, called the **synaptic cleft,** located between the neuron and the muscle cell membranes (sarcolemma).



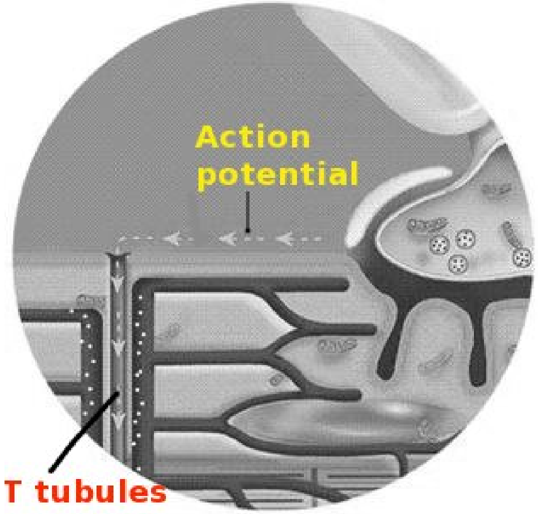
Acetylcholine (Ach) diffuses through the synaptic cleft and binds to **Ach receptors** on the muscle cell membrane (**sarcolemma**).



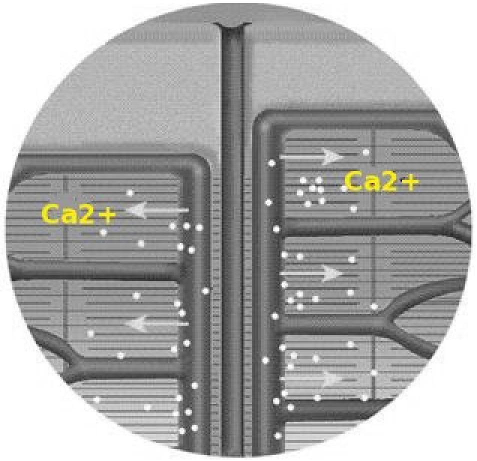
When acetylcholine (Ach) binds, the Ach receptor on the muscle cell membrane changes from a closed shape to an open shape. **Sodium (Na+)** will diffuse into the muscle cell through this same channel, and a moment later, **potassium (K+)** will diffuse out of the cell. This flow of charged particles briefly creates a small electric charge across the muscle cell membrane called an end plate potential (EPP).



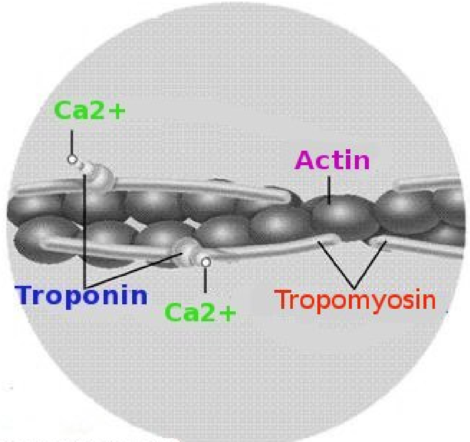
When this electrical charge is present, the muscle is in the depolarization phase of the end plate potential (EEP). Once the EEP begins, this sets off the release of additional **sodium (Na+)** from adjacent regions of the **sarcolemma**. This causes nearby **sodium (Na+)** channels on the muscle cell membrane to open, and the process spreads along the **sarcolemma**. This begins the action potential in muscle fiber



An **action potential** will travel across the muscle cell membrane, or sarcolemma, and down the tubes **(T tubules)** to penetrate the inside of the muscle cell. Recall that the sarcolemma contains the sarcoplasmic reticulum. The sarcoplasmic reticulum is a network of membranes and tubules that run from the sarcolemma and lies over and in between the sarcomeres.

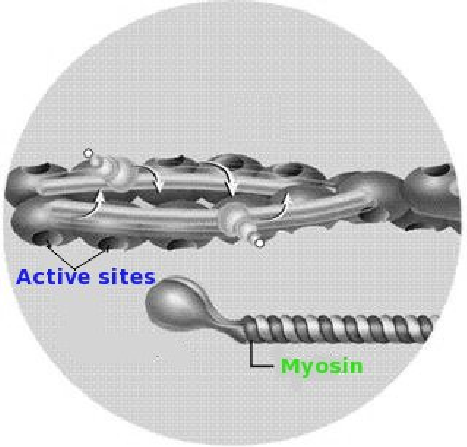


The action potentials traveling over the T tubules cause **calcium (Ca2+)** channels on the sarcoplasmic reticulum to open. This allows **calcium ions,** which are stored within the sarcoplasmic reticulum, to diffuse out of the sarcoplasmic reticulum and into the sarcoplasm(cytoplasm) of the muscle cell.



Thin filament

In the sarcoplasm, **calcium (Ca2+)** binds to troponin on the **thin filament.**



The **troponin** proteins change shape, and drag the **tropomyosin** off of the **active sites** on the G **actin.** As soon as the active sites are exposed, the **myosin** heads of the thick filaments can bind to the G actin of the thin filament.

To recap, action potentials arrive at the synaptic knob causing calcium channels to change from an open to closed shape. Calcium ions diffuse into the synaptic knob.

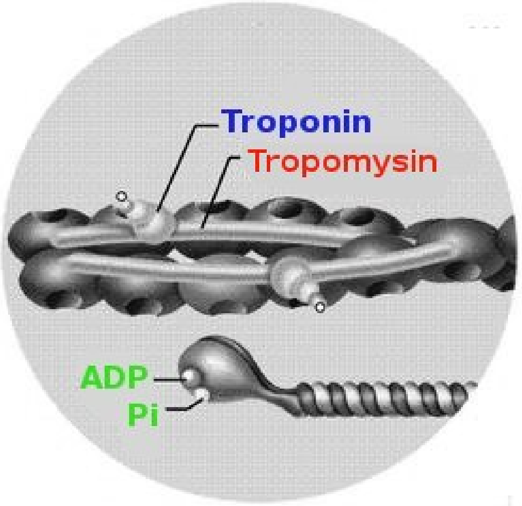
These calcium ions then attach to proteins causing the protein to change from an inactive to an active state. Once activated, the protein moves the synaptic vesicles which fuse with the cell membrane causing the synaptic vesicles to release acetylcholine (ACh). The ACh binds to receptors on the sarcolemma (cell membrane) and they open up. Sodium then enters and depolarizes this region of the cell and then the potassium enters causing a repolarizing. This depolarizing and repolarizing process is called the end plate potential.

Diffusion of sodium and potassium through their separate channels depolarizes the membrane and initiates the action potential in muscle fiber. The action potential travels down the T tubules to the interior of the muscle fiber causing calcium channels on the sarcoplasmic reticulum to open, releasing the calcium into the muscle cell. The calcium then binds with the troponin and shifts position exposing the active sites where actin binds to the myosin.

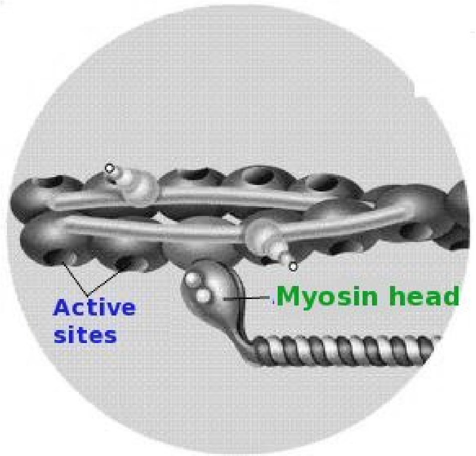
The previous instruction showed us how the nervous system stimulates a muscle contraction, how this stimulation leads to the release of calcium from the sarcoplasmic reticulum, and the shortening of the sarcomeres. The next part to the instruction will examine what happens during muscle contraction.

The Sliding Filament Mechanism of Muscle Contraction

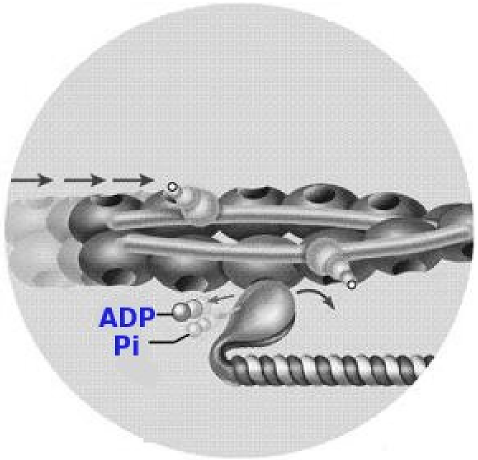
Contracting a muscle requires energy, and this energy is provided by a molecule called ATP (adenosine triphosphate). When the chemical bonds in ATP are broken down to provide energy, ATP is transformed into new molecules of **ADP (adenosine diphosphate)** and **Pi**. During this transformation of ATP to ADP, energy is released which can be used to do work.



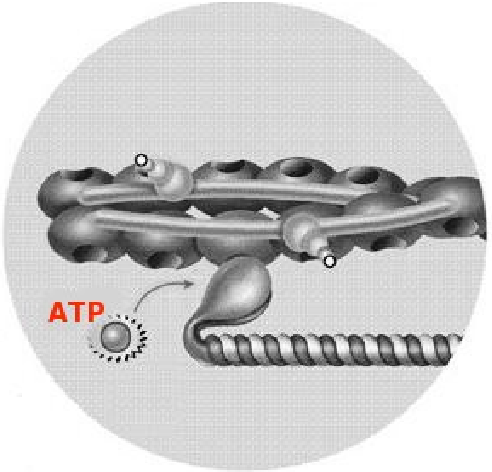
Activation occurs when the ATP molecule bound to the myosin head is transformed to **ADP** and **Pi**. The energy that was released during activation was used to bend the myosin head back like a spring, so that it is ready to bind to an active site on G actin as soon as **tropomyosin** is dragged out of the way.



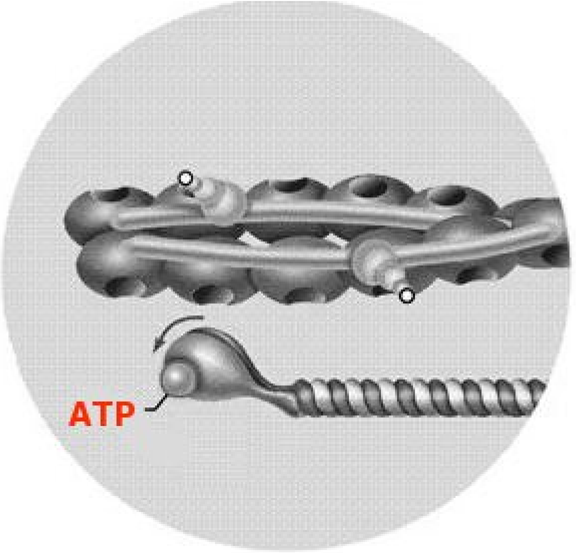
Remember that the myosin heads of the thick filaments are hinged. The **myosin heads** spring up and attach to the **active site** on G actin. This is called cross-bridge formation



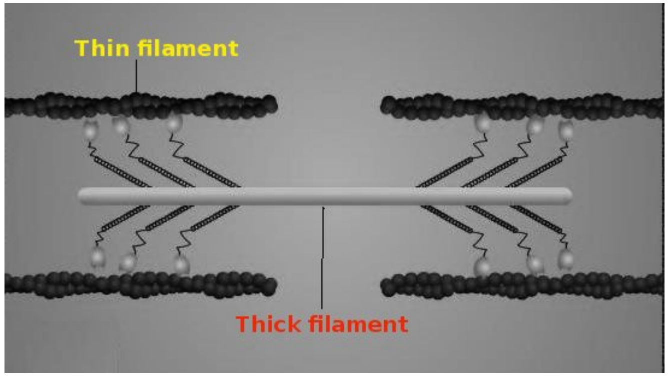
Immediately after cross-bridge formation, the myosin head bends further and pull an actin filament toward the center of the sarcomere. This pulls the thin filament along the thick filament. During this power stroke, the **ADP** and **Pi** left over from breaking down **ATP** earlier is released from the myosin head. Power stroke helps to move medially toward the middle of the sarcomere. All of the sarcomeres of a cell move together to make the cell contracts.



Myosin head will remain in a flexed position until a new **ATP** molecule binds to the myosin head.



When the new **ATP** molecule binds, the myosin head will change shape and detach from the active site. The **ATP** molecule is immediately broken down to **ADP**. The energy that is released is used to bend the myosin head back to its activated “cocked” position and the cycle can begin again and move to the next active site.



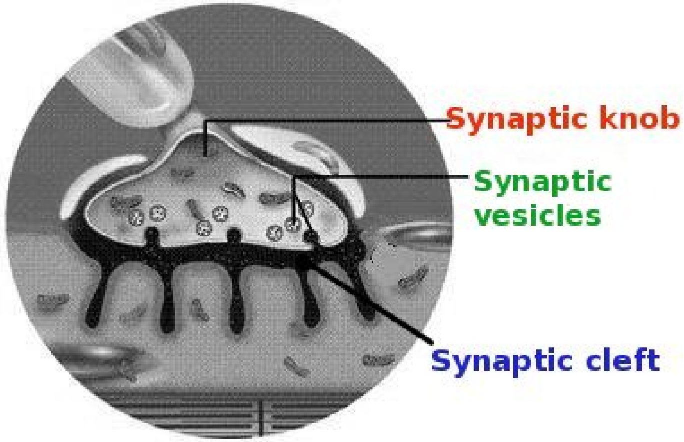
This cycle will continue for as long as the active sites on the G actin are exposed. The myosin heads on both ends of the **thick filaments** will move from one active site to the next active site, and keep pulling the **thin filaments** of the sarcomere inward, thus shortening the sarcomere. As all the sarcomeres in the muscle cell become shorter, the muscle cell itself becomes shorter. When many muscle cells in a skeletal muscle are contracting, the entire muscle shortens and moves or stabilizes bones.

To summarize, there are several processes involved in muscle contraction.

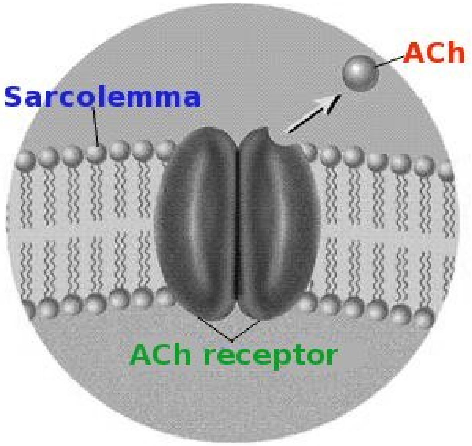
First, ATP is transformed to ADP, and releases energy that is used to bend the myosin head back to the ready position. Then during cross bridge formation the heads of myosin molecules attach to active sites on G actin. The heads of myosin molecules bend and pull thin filaments toward center of sarcomere with a power stroke. Then during cross bridge detachment, ATP binds to myosin and myosin heads separates from G actin. This cycle will continue for as long as the active sites on the G actin is exposed causing the muscle to contract (become shorter). Once a muscle has contracted, other processes must occur for the muscle to relax. These processes are described in the following section.

. Relaxation

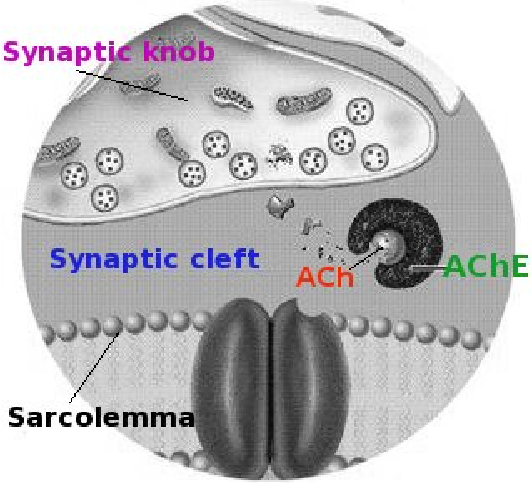
When the muscle cells relax, the sarcomeres within each muscle cell return to their original length. Skeletal muscle is under your voluntary control. You can choose to stop sending action potentials down your motor neurons.



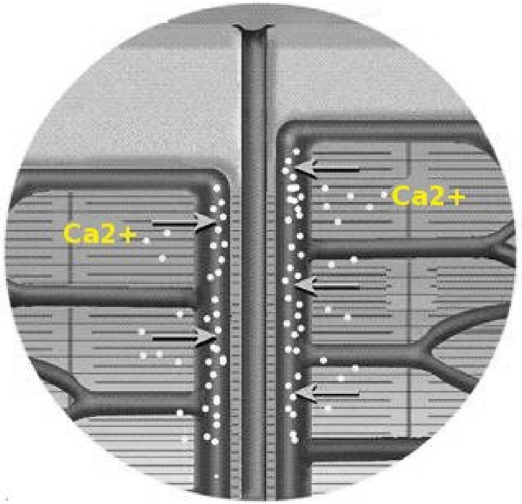
When action potentials (signals) stop arriving at the **synaptic knob** of the motor neuron, the calcium channels close. ATP driven calcium, pumps and transports any calcium in the cytoplasm out of the cell. With no calcium inside the cell, the proteins responsible for moving **synaptic vesicles** to the membrane become inactive and acetylcholine (ACh) is no longer released into the **synaptic cleft.**



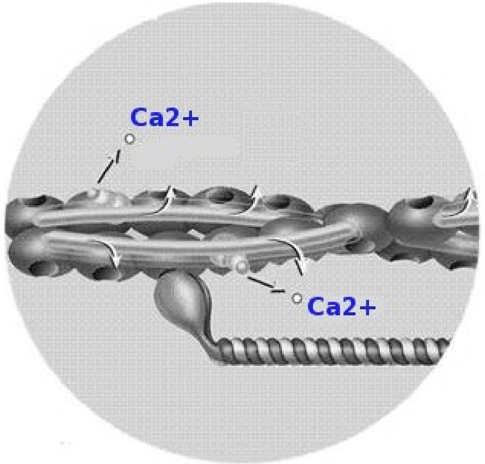
The **Acetylcholine (ACh)** then dissociates from **ACh receptors** on the **sarcolemma.**



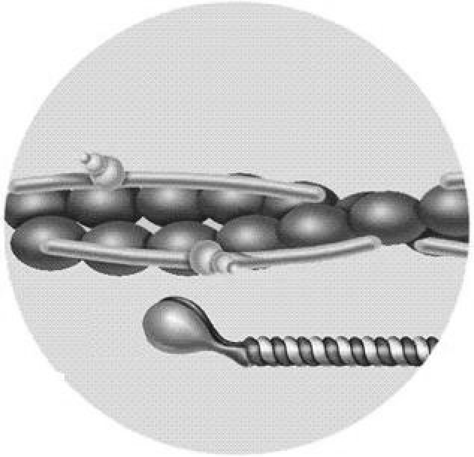
Without any new acetylcholine **(Ach)** entering the **synaptic cleft, acetylcholine esterase (AChE)** breaks down the free **ACh** molecules. Other **ACh** molecules are absorbed into the **synaptic knob** of the membrane, and some **ACh** molecules just diffuse away. Without any **ACh** in the **synaptic cleft,** muscle stimulation ceases.



Once muscle stimulation ceases, action potentials traveling over the muscle cell membrane and down the T tubules also stop. This causes the calcium channels in the sarcoplasmic reticulum to close. ATP driven calcium pumps actively transport **calcium (Ca2+)** out of the sarcoplasm and back into the sarcoplasmic reticulum, causing the calcium concentration in the sarcoplasm to decrease.



As **calcium (Ca2+)** levels in the sarcoplasm drop lower and lower, the troponin changes back to its original shape, and drags tropomyosin back over the active sites on the G actin molecules.



With the active sites on G actin are covered by tropomyosin, the myosin heads of the thick filament can no longer form cross-bridges. Without cross-bridge formation, the thick and thin filaments slide past each other as the sarcomere expands to its original length. As every sarcomere in the muscle cell does this, the entire cell lengthens and the muscle relaxes.

To recap, relaxation occurs when the sarcomeres within each muscle cell return to their original length, which is under voluntary control. Action potential signals stop arriving at the synaptic knob causing the voltage gated calcium channels to close. The Acetylcholine (ACh) release then ceases causing free ACh to be broken down by acetylcholine esterase (AChE). ACh fragments are reabsorbed by the synaptic knob. Muscle stimulation ceases. Calcium ions are transported back into the sarcoplasmic reticulum causing the calcium concentration to decrease. As the calcium decreases, it dissociates from the troponin which then changes back to its original shape. The tropomysin is pushed back over the G actin molecules so that cross bridges can no longer be formed causing muscle relaxation.

You have reached the end of the instruction. You were first given a comprehensive overview of the muscle structure and they physiology of the muscle fiber (cell). You then learned about how the nervous system stimulates a muscle contraction, how this stimulation leads to the release of calcium from the sarcoplasmic reticulum, and the shortening of the sarcomeres. We then discussed muscle contraction and concluded with instruction on muscle relaxation. Please review any sections that you do not understand and move on to the next part.