Chapter 5
Intrinsic and Extraneous Cognitive Load

Learners must process instructional information in working memory. The load imposed on working memory by that instructional information can be divided into categories depending on its function (Paas, Renkl, & Sweller, 2003, 2004; Sweller, van Merriënboer, & Paas, 1998; van Merriënboer & Sweller, 2005). Some of the working memory load is imposed by the intrinsic nature of the information and that load is called 'intrinsic cognitive load'. It is imposed by the basic structure of the information that the learner needs to acquire for achieving learning goals irrespective of the instructional procedures used.

Another category of cognitive load that requires working memory resources is imposed not by the intrinsic structure of the information but rather by the manner in which the information is presented or the activities in which learners must engage. In other words, as well as the nature of the instructional material, the nature of the instructional design used to present the material can impose a cognitive load that under many circumstances can be unnecessary. In the case of the instructional design, where the load is unnecessary and extraneous to the learning goals, it is called 'extraneous cognitive load'. This load is imposed solely because of the instructional procedures being used.

The cognitive load imposed by the intrinsic nature of the material (intrinsic cognitive load) and the manner in which the material is presented (extraneous cognitive load) both must be dealt with by working memory with resources allocated to both of these two sources of cognitive load. Resources devoted to the load imposed by the intrinsic nature of the material are germane to learning and so can be referred to as 'germane resources'. The term, 'germane cognitive load' is frequently used to refer to germane resources although it is probably inappropriate to use this term. Unlike intrinsic and extraneous cognitive load that are imposed by the nature and structure of the learning materials, germane cognitive load is not imposed by the learning materials. Rather, it belongs to a different category that can be better understood as working memory resources that are devoted to information that is relevant or germane to learning. Such information imposes an intrinsic cognitive load. In a similar manner, extraneous cognitive load, imposed by the instructional design used, must also be allocated working memory resources. Working memory resources devoted to information that is imposed solely by the

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instructional design can be referred to as ‘extraneous resources’ that must deal with extraneous cognitive load.

Additivity of Intrinsic and Extraneous Cognitive Load

Intrinsic and extraneous cognitive load are additive. Together, they determine the total cognitive load imposed by material that needs to be learned. That total cognitive load determines the required working memory resources needed to process the information with some resources dealing with intrinsic cognitive load (germane resources) and other resources dealing with extraneous cognitive load (extraneous resources). While resources are devoted to dealing with either intrinsic or extraneous cognitive load those resources come from the same undifferentiated working memory pool.

If the working memory resources required to deal with the load imposed by intrinsic and extraneous cognitive load exceed the available resources of working memory, the cognitive system will fail, at least in part, to process necessary information. Germane resources will be too low to deal with the intrinsic cognitive load imposed by the learning materials. Indeed, if the instructional design is particularly poor resulting in a very high extraneous cognitive load, there may be insufficient resources to even move beyond the barrier of the poor instructional design and begin to devote germane resources to intrinsic cognitive load. Learners may not even commence learning because the entire pool of working memory resources is needed to deal with the instructional processes used.

One aim of instructional design is to reduce extraneous cognitive load so that a greater percentage of the pool of working memory resources can be devoted to issues germane to learning rather than to issues extraneous to learning. Extraneous cognitive load should be reduced as far as possible, thus reducing working memory resources devoted to extraneous issues and increasing the availability of germane resources devoted to intrinsic cognitive load.

Element Interactivity

Levels of both intrinsic and extraneous cognitive load are determined by element interactivity. Interacting elements are defined as elements that must be processed simultaneously in working memory because they are logically related. An element is anything that needs to be learned or processed, or has been learned or processed. Elements are characteristically schemas. Most schemas consist of sub-schemas or sub-elements. Prior to a schema being acquired, those sub-elements must be treated as individual elements in working memory. After they have been incorporated into a schema, that schema can be treated as a single element in working memory. Thus, learning reduces working memory load by converting multiple lower-level schemas into a smaller number of higher-level schemas or even a single higher-level schema that can be treated as a single entity.

With respect to intrinsic cognitive load, some material can be learned one element at a time and so is low in element interactivity and low in intrinsic cognitive load. Such material requires few working memory resources. Other material has elements that cannot be learned in isolation. The elements interact and so they must be processed simultaneously rather than as single, unrelated elements because they cannot be understood as single elements. Such material is high in element interactivity and high in intrinsic cognitive load. High element interactivity material requires more working memory resources than material that is low in element interactivity until the interacting elements have been incorporated into a schema after learning.

Extraneous cognitive load also is determined by levels of element interactivity but, in this case, element interactivity that is unnecessary for achieving learning goals. Some instructional procedures require learners to process only a limited number of such elements simultaneously. In this case, element interactivity is low and extraneous cognitive load is low. Different instructional designs require learners to process a large number of elements simultaneously resulting in high element interactivity and a high extraneous cognitive load. The manner in which element interactivity influences intrinsic and extraneous cognitive load will be discussed next.

Element Interactivity and Intrinsic Cognitive Load

As indicated above, this source of cognitive load is intrinsic to the information that the learner must deal with (Sweller, 1994) and is entirely determined by levels of element interactivity. Element interactivity can be estimated for any information that students may be required to learn. We will begin with examples of low element interactivity information.

Acquiring a new vocabulary is a common necessity in many disciplines. Learning the new vocabulary of a second language provides an obvious example but acquiring a new vocabulary, to a greater or lesser extent, is likely to be a requirement of all areas. In chemistry for example, the symbols of each of the elements of the periodic table must be learned. For many vocabulary items of a discipline, each of the elements can be learned in isolation with no consequences for, and no relation to, any of the other elements that must be learned. For example, a chemistry student can learn that the symbol for copper is Cu quite independently of learning that the symbol for iron is Fe. Similarly, a second language student can learn that the translation of the English word ‘cat’ is the French word ‘chat’, independently of learning that the translation of the English word ‘dog’ is the French word ‘chien’. In each case there are no logical or structural reasons why learning one relation should have any impact on learning other relations. As a consequence, these categories of relations do not need to be learned simultaneously. They can be learned independently at different times and without reference to each other because the learning elements do not interact. Learning these relations provides an example of low element interactivity material.

High element interactivity information consists of elements that are closely related to each other and so cannot be learned in isolation. The elements interact in a manner that renders learning individual elements in isolation meaningless. All relevant elements must be processed simultaneously in order to be learned in a meaningful fashion. For example, while we can learn chemical symbols in isolation, we cannot learn in isolation the various ways those symbols are manipulated in a chemical equation such as $MgCO_3 + H_2SO4 \rightarrow CO_2 + MgSO_4 + H_2O$. We need to consider the entire equation, including all of the elements that constitute the equation, whenever any manipulation occurs.

Indeed, equations in general, by their very nature are high in element interactivity. We can see the effect of high element interactivity by considering simple algebra equations. Assume someone is learning to solve equations of the form, $(a + b)/c = d$, solve for a. This equation includes a large number of interacting elements. The symbols of the equation such as a, b, =,/, etc. provide obvious elements but there are many more elements than the symbols. All of the relations between all of the symbols also constitute elements that must be processed when learning to solve equations. As an example, the symbol '/' and the symbol, 'c', have a particular relation that must be processed and understood in order to learn how to solve this problem. The relation between '/' and 'c' constitutes an element that must be learned. Furthermore, that element itself interacts with all of the other elements in the problem whether those elements consist of symbols or other relations between symbols. The number of interacting elements incorporated in the problem $(a + b)/c = d$, solve for a is large and because they interact all elements must at some point be considered simultaneously. Learning to solve algebra equations is a high element interactivity task because there are many elements that must be processed simultaneously.

A full understanding of high element interactivity material cannot occur without simultaneously processing all of the elements that constitute the task. We cannot, for example, process the '/' symbol in the previous equation, in isolation, without reference to the other symbols and relations between the symbols. We need all of the other symbols and relations to confer meaning on the '/' symbol. The equation only can be fully understood by processing all of the relevant symbols and relations simultaneously. Furthermore, to solve the problem, the symbols and relations must be related to the entire problem statement and its possible solution. Unless all of the interacting elements are processed simultaneously, high element interactivity material cannot be understood because considering individual elements in isolation tells us little of relevance to the problem and its solution.

The level of interactivity between elements of information that are essential for learning determines intrinsic cognitive load. If element interactivity is low, intrinsic cognitive load also will be low because only a small number of elements and relations will need to be processed simultaneously in working memory. At the extreme, individual elements can be learned independently of all other element and no element imposes a high working memory load resulting in a very low intrinsic cognitive load. In contrast, if the level of interactivity between essential elements is high, intrinsic cognitive load will also be high.

Task Difficulty

A low intrinsic cognitive load needs to be distinguished from levels of task difficulty. A task may have a very low intrinsic cognitive load imposing a very low load on working memory but still be very difficult. Learning the vocabulary of a second language provides a clear example. Natural languages have a great number of vocabulary items that need to be learned. Learning those vocabulary items can be a difficult, time-consuming task that frequently takes many years. The difficulty of the task is driven by the large number of items, not the complexity of the items. Each vocabulary item may be acquired with little working memory load if it is low in element interactivity and so imposes a low intrinsic cognitive load. Difficulty in learning some material such as second language vocabulary items derives from the many individual elements that need to be learned, and not from any difficulty associated with each element.

While a low element interactivity task is only difficult if there are many elements that must be processed sequentially as in the case of acquiring the vocabulary of a second language, a high element interactivity task may be difficult even if the number of relevant elements is relatively low. But the reason for task difficulty when dealing with high element interactivity material such as the algebra equation presented above is usually very different to the reason low element interactivity material may be difficult. A small number of elements, if they interact, can be very difficult to process in a capacity constrained working memory. A large number of interacting elements can be impossibly difficult for some people. The difficulty of learning novel, high interactivity material can derive from two unrelated sources. High interactivity material always is difficult because of element interactivity. It also may include a large number of elements, although the total number of elements does not contribute directly to element interactivity. Thus, some high element interactivity material can be difficult to learn not only because it may consist of a large number of interacting elements but also because it consists of many elements in absolute terms. Material that includes both a very large number of elements with many of those elements interacting will be exceptionally difficult to learn.

The total number of elements and the extent to which they interact can vary independently and so the total number of elements has no relation to the intrinsic cognitive load unless the elements interact. Learners may need to assimilate literally thousands of elements but face a relatively insignificant intrinsic cognitive load if low element interactivity allows individual elements to be processed independently of each other. The task of assimilating many elements is in itself difficult even if they do not interact, but processing any individual element is not difficult. In contrast, a relatively small number of interacting elements can impose an overwhelming intrinsic cognitive load because in order for the information to be understood, all elements need to be processed simultaneously and simultaneously processing several elements may exceed working memory limits. The resultant, excessive intrinsic cognitive load requires particular instructional strategies. Those strategies will be discussed in Part IV.

Understanding

Element interactivity can be used to define 'understanding' (Marcus, Cooper, & Sweller, 1996). Information is fully understood when all of its interacting elements can be processed in working memory. A failure to understand occurs when appropriate elements are not processed in working memory. Information is difficult to understand when it consists of more interacting elements than can readily be processed in working memory. Low element interactivity information is easy to understand because it can easily and appropriately be processed in working memory.

The relation between element interactivity and understanding can be seen clearly when we consider the language we use when dealing with low element interactivity information. Low element interactivity material does not have the term 'understanding' attached to it. Assume someone cannot tell us that Cu is the chemical symbol for copper. We assume that they either have not learned the symbol or have forgotten it and we will refer to their failure as a lack of knowledge or a failure of memory. It would be seen as peculiar to refer to the failure in the context of understanding. If someone cannot tell us that the chemical symbol for copper is Cu, we are unlikely to attribute the failure to a lack of understanding. The term is inappropriate in this context.

The contrast is marked when we deal with high element interactivity information. The term 'understanding' only applies to high element interactivity material associated with a high intrinsic cognitive load. It is never used when dealing with low element interactivity material that imposes a low intrinsic cognitive load. Consider a student who has failed to solve the problem $(a + b)/c = d$, solve for a. Similar to materials with low element interactivity, that failure is due to a lack of knowledge or a failure of memory. The student has never learned to solve this category of problems or has forgotten how to solve them but in this case, most people are likely to assume that a failure of understanding has occurred. Information is 'understood' when we are able to process multiple, interacting elements simultaneously in working memory. We fail to understand information when the number of multiple, interacting elements is too large to permit us to process all of the elements in working memory. In the case of the above algebra example, students may be unable to understand how to solve this problem if they are unable to process all of the pro-numerals, symbols and relations between them in working memory.

The distinction between learning with understanding and learning by rote can be explained by element interactivity. Learning by rote tends to have strong negative connotations while learning with understanding has equally strong positive connotations.

Both forms of learning can be explained by processes of element interactivity in working memory. While learning with understanding is reserved for high element interactivity information, learning by rote can be applied to either low or high element interactivity information. When dealing with low element interactivity information, we assume, correctly, that learning by rote is unavoidable because no other form of learning is available. If learning chemistry, we have no choice but to rote learn that the symbol Cu stands for copper. In contrast, high element interactivity material can be either rote learned or learned with understanding and so the differential connotations associated with learning by rote or learning with understanding apply. However, we need to understand the solution to the problem $(a + b)/ = c$, solve for a to enable us to create more complex schemas in this domain. We should not rote learn the solution.

The distinction between learning by rote and learning with understanding in element interactivity terms will be exemplified by considering a child learning the concept of multiplication. Multiplication can be learned in the same way as a new vocabulary with each multiplicative value stored in long-term memory. A child can rote learn that $3 \times 4 = 12$. There are several advantages to rote learning with a major one being an immense reduction in element interactivity and a commensurate reduction in working memory load. Rote learning that $3 \times 4 = 12$ is likely to require no more than five elements consisting of the five symbols that constitute the expression.

Understanding why $3 \times 4 = 12$ also requires knowing the outcome of the procedure but, in addition, it requires processing much more information in working memory and storing that information in long-term memory, resulting in a considerable increase in element interactivity. Rather than merely learning that $3 \times 4 = 12$, learners need to understand that the reason the answer to the multiplication is 12 is because 4 is added 3 times. Not only does $3 \times 4 = 12$, but $4 + 4 + 4 = 12$ and the fact that both arithmetic operations give an answer of 12 is not a coincidence. The multiplication equation means adding 3 lots of 4. To begin to understand the multiplication equation as opposed to merely rote learning it, the elements associated with $4 + 4 + 4 = 12$ must be added to, and interact with, the elements associated with $3 \times 4 = 12$. Element interactivity and its associated cognitive load must be substantially increased. Additional understanding along with additional element interactivity and working memory load occur when students learn that $3 \times 4 = 4 + 4 + 4 = 3 + 3 + 3 + 3 = 4 \times 3 = 12$. Learning relations between addition, subtraction, multiplication and division results in further understanding, further element interactivity and further working memory load. Many learners cease adding additional interacting elements beyond $3 \times 4 = 12$ because of the dramatic increase in element interactivity and cognitive load that is required when learning with understanding. This failure to go beyond the basic knowledge ($3 \times 4 = 12$) means that learners will not at this point learn the commutative law of multiplication ($a \cdot b = b \cdot a$) and how the commutative law might be applied to other numbers (e.g. $2 \times 5 = 5 \times 2$). Hence schema formation is limited by not learning further relations and connections within the multiplication system.

Based on this analysis, learning by rote and learning with understanding require the same qualitative processes. In both cases, information must be processed in working memory prior to being stored in long-term memory. The differences are quantitative, not qualitative. Learning with understanding always increases the number of interacting elements that must be processed in working memory. For all of us, under at least some circumstances, the increase in element interactivity and working memory load associated with understanding information may be too large to handle. Learning by rote without understanding may be the only viable option. Learning with understanding should always be the goal of instruction, but as instructors we need to understand that sometimes that goal will not be achievable. Rote learning may be the only available option, at least in the initial stages of learning.

From an instructional perspective, we can see that under some circumstances, it may not be possible for very high element interactivity material to be simultaneously processed in working memory because working memory limits may be exceeded. Such information cannot be understood, at least initially. An initial failure to understand does not mean the information cannot be processed. Processing can occur, individual element by individual element or by small groups of elements. We label such processing conditions as learning by rote. Rote learning may be unavoidable during the initial stages of learning very high element interactivity material (Pollock, Chandler, & Sweller, 2002). This issue will be explored further, in conjunction with empirical evidence, when discussing the isolated–interacting elements effect in Chapter 16.

Altering Intrinsic Cognitive Load

In one sense, intrinsic cognitive load cannot be altered because it is intrinsic to a particular task. If the learning task is unaltered and if the knowledge levels of the learners remain constant, intrinsic cognitive load also will remain constant. That constant or fixed cognitive load can be altered by changing the nature of the learning task. For example, it was pointed out above, that if interacting elements are taught as though they are isolated with each element treated as though it bears no relation to other elements, element interactivity and intrinsic cognitive load can be reduced. Of course, the reduction in intrinsic cognitive load only has been accomplished by changing the task. Learners no longer are taught the relations between interacting elements, a major component of intrinsic cognitive load. That may not matter during early learning, but for most subject matter full understanding including the relations between interacting elements is likely to be essential at some point. Reducing intrinsic cognitive load by altering the nature of what is learned may be an important instructional technique, but in most cases its utility is likely to be temporary.

Intrinsic cognitive load also will be reduced by the act of learning itself. Learning includes converting a group of interacting elements that are treated as multiple elements in working memory into a smaller number or even a single element. Almost any instance of learning provides an example. To people not familiar with the Latin alphabet and English, 'CAT' is likely to provide a complex set of squiggles that overwhelm working memory. To readers of this text, of course, with schemas for 'CAT', the interacting elements are buried in the schema and the intrinsic cognitive load is negligible. A major function of learning is to dramatically reduce element interactivity and intrinsic cognitive load by incorporating interacting elements in schemas. The resultant reduction in cognitive load frees working memory resources for other activities. In the present case of reading this text, because working memory resources are not devoted to decoding the text, they can be used to interpret the content, the ultimate aim of learning to read. Thus, learning through schema acquisition eliminates the working memory load imposed by high element interactivity information.

Apart from altering what is learned or the act of learning itself, intrinsic cognitive load cannot be altered. For a particular task presented to learners with a particular level of knowledge, intrinsic cognitive load is fixed.

It can be seen that the concept of element interactivity is closely tied to the overlapping definitions of elements and schemas. An element is anything that needs to be learned or processed while schemas are usually multiple, interacting elements. Schema construction consists of learning how multiple elements interact while schema automation allows those interacting elements to be ignored when using a schema. Once a schema has been constructed, it becomes another, single, element that does not impose a heavy working memory load and can be used to construct higher-order schemas. The interacting elements are embedded in a schema that can be treated as a single element in the construction of more complex schemas. While a written word consists of a complex set of interacting lines and curves that someone unfamiliar with the written English language may have difficulty interpreting or even reproducing, to a fluent reader those interacting elements are embedded in a schema that itself acts a single element.

Relations of Intrinsic Cognitive Load to Human Cognitive Architecture

Novel, unfamiliar information that needs to be learned is governed by the borrowing and reorganising, randomness as genesis and narrow limits of change principles. These principles describe how novel information is acquired. Once learned, information that needs to be used is governed by the information store and the environmental organising and linking principles. These principles describe how familiar, stored information is used to govern activity.

Learned, familiar information is treated quite differently from novel, yet-to-be-learned information. As indicated when discussing the narrow limits of change and the environmental organising and linking principles, the characteristics of working memory are very different when dealing with unfamiliar and familiar information. Those differences now can be considered from the perspective of the manner in which high element interactivity information is handled. Novel, high element interactivity information that is yet to be learned is likely to impose a high intrinsic cognitive load that may overwhelm working memory when it is being acquired via the borrowing and reorganising or randomness as genesis principles. That same information, once learned and stored in long-term memory as a schema with its interacting elements incorporated in the schema, can be retrieved from the information store using the environmental organising and linking principle. In contrast to the difficulty in processing the elements of that information when a schema is being constructed, once it has been constructed and stored in long-term memory, it can be retrieved as a single rather than multiple elements from long-term memory to govern activity. The multiple, interacting elements are embedded within a schema and it is that schema that is retrieved from long-term memory. Processing a single schema as a single element is likely to impose a minimal working memory load.

Element Interactivity and Extraneous Cognitive Load

Element interactivity is associated with extraneous as well as intrinsic cognitive load. Unlike intrinsic cognitive load that is imposed by the intrinsic nature of the information that learners must acquire, extraneous cognitive load is imposed on working memory due to the manner in which information is presented during instruction. Some instructional procedures require learners to process a large number of interacting elements many of which are not directly relevant to learning through schema acquisition. Other procedures, in presenting the same information for learners to acquire, substantially reduce this element interactivity. While detailed information concerning element interactivity associated with extraneous cognitive load will be presented in the chapters of Part IV, preliminary information will be presented in this section.

It may be recalled that based on the borrowing and reorganising principle, the acquisition of biologically secondary information is assisted by direct, explicit instruction. (We have evolved to acquire biologically primary knowledge without explicit instruction.) Let us assume that instead of direct, explicit instruction, problem solving is used as an instructional tool. Learners must acquire knowledge by discovering solutions to problems that they have been presented. Students might, for example, be learning mathematics by the common technique of solving problems. Solving novel problems for which a solution is not available in long-term memory requires the use of a means–ends strategy. As indicated in Chapters 7 and 8 on the goal-free and worked example effects, that strategy requires problem solvers to simultaneously consider the current problem state (e.g. $a + b = c$), the goal state (make a the subject of the equation), to extract differences between the current state and the goal state (the term '$+b$' is located on the left-hand side of the equation and needs to be eliminated) and to find problem-solving operators (rules of algebra) that can be used to eliminate the differences between the current state and the goal state (subtract b from both sides of the equation). The problem cannot be solved unless all of these elements are considered. Element interactivity is very high when using a means–ends strategy because the strategy necessarily involves processing several elements.

Furthermore, those elements cannot be considered in isolation. We cannot extract differences between a given problem state and a goal state without simultaneously considering the given state, the goal state, the differences between them and the problem-solving moves that might reduce those differences.

There are alternatives to using a high element interactivity means–ends strategy. Rather than having learners solve problems, they could be presented with worked examples that completely eliminate a means–ends strategy because learners are no longer engaged in problem solving. Whether learners engage in problem solving or in studying worked examples is under the control of instructors and so the high element interactivity associated with means–ends problem solving is an example of extraneous cognitive load that can and should be reduced. The consequences of using problem solving rather than worked examples will be discussed in detail in Chapter 8. There are many other examples of element interactivity resulting in a high extraneous cognitive load that will be discussed in the chapters of Part IV.

This argument is closely tied to the structures of human cognitive architecture. If instruction requires learners to engage in problem-solving search via the randomness as genesis principle, or if it includes other cognitive activities that are similarly unfavourable to schema acquisition and automation, then the effectiveness of that instruction will be reduced due to working memory limitations associated with the narrow limits of change principle. Problem-solving search along with a variety of other cognitive activities associated with some instructional procedures imposes a heavy extraneous cognitive load that can interfere with learning.

While it is never advantageous to increase extraneous cognitive load, it can be advantageous to increase intrinsic cognitive load. Increasing intrinsic cognitive load increases the amount of information that needs to be processed and learned, and providing working memory capacity is available that increase is likely to be beneficial (see the variability effect in Chapter 16). In contrast, an increase in extraneous cognitive load results in learners using scarce working memory resources for purposes other than learning. Since extraneous cognitive load normally is under the control of the instructor, it can be reduced by altering instructional procedures and without compromising understanding. Understanding is likely to be increased if a reduction in extraneous cognitive load frees working memory resources for schema acquisition and automation.

Instructional Implications

Total cognitive load, consisting of intrinsic and extraneous cognitive load, must not exceed working memory resources. If total cognitive load is too high, processing necessary information may become difficult and so learning may cease. For given learners and given information, intrinsic cognitive load cannot be altered. It can be increased or decreased by changing the nature of what is learned. If the intrinsic cognitive load is high, the level of extraneous cognitive load can become critical. Reducing extraneous load is much more important when intrinsic cognitive load is high than when it is low. A high extraneous cognitive load may not matter a great deal if intrinsic cognitive load is low because the total cognitive load may be less than available working memory resources. In other words, for material with a low element interactivity and therefore low intrinsic cognitive load, learners nevertheless will be able to process the information. A less than optimal instructional design associated with low intrinsic cognitive load due to low element interactivity may therefore not interfere with learning. The total cognitive load still may be within working memory limits.

If intrinsic cognitive load is high, adding a high extraneous cognitive load to an already high intrinsic cognitive load may well result in an excessive total load. Under high intrinsic cognitive load conditions, instructional design issues may be important, unlike low intrinsic cognitive load conditions. Adding the high element interactivity associated with a high intrinsic cognitive load to the high element interactivity associated with a high extraneous cognitive load may exceed available working memory resources. Devoting working memory resources to dealing with an inappropriate instructional design may not matter when intrinsic cognitive load is low. It may be critical when intrinsic cognitive load is high (see Chapter 15 on the element interactivity effect). As a consequence, most of the cognitive load effects discussed in the chapters of Part IV are concerned with conditions under which both intrinsic and extraneous cognitive load are high and so need to be reduced. Cognitive load theory has been concerned primarily, though not exclusively, with reducing extraneous cognitive load.

Conclusions

Cognitive load imposed by instructional materials can be divided into intrinsic and extraneous cognitive load. Equivalently, working memory resources can be divided into germane resources that deal with intrinsic cognitive load and extraneous resources that deal with extraneous cognitive load. This division has proved to be basic to the development of cognitive load theory. The primary, though not sole, aim of cognitive load theory has been to devise instructional procedures that reduce extraneous cognitive load and so decrease the working memory resources that must be devoted to information that is extraneous to learning. Working memory resources that no longer need to be devoted to dealing with extraneous cognitive load can instead be diverted to dealing with intrinsic cognitive load that is germane to the learning process.

Most of the cognitive load effects discussed in Part IV of this book are concerned with instructional procedures that reduce extraneous cognitive load. When dealing with extraneous cognitive load, it is always advantageous to reduce it and never advantageous to increase it. A smaller number of the cognitive load effects are concerned with altering intrinsic cognitive load rather than reducing extraneous cognitive load. It can be advantageous to increase or decrease intrinsic cognitive load depending on whether intrinsic cognitive load exceeds available working memory resources or under-utilises those resources. The cognitive load effects discussed in Part IV were all based on the assumption that extraneous cognitive load should be reduced while intrinsic cognitive load should be optimised. In order to describe ideal levels of cognitive load, we first need to discuss techniques for measuring cognitive load. The next chapter is concerned with this issue.