

## mat.1 Introduction

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The development of the axiomatic method is a significant achievement in the history of science, and is of special importance in the history of mathematics. An axiomatic development of a field involves the clarification of many questions: What is the field about? What are the most fundamental concepts? How are they related? Can all the concepts of the field be defined in terms of these fundamental concepts? What laws do, and must, these concepts obey?

The axiomatic method and logic were made for each other. Formal logic provides the tools for formulating axiomatic theories, for proving theorems from the axioms of the theory in a precisely specified way, for studying the properties of all systems satisfying the axioms in a systematic way.

**Definition mat.1.** A set of sentences  $\Gamma$  is *closed* iff, whenever  $\Gamma \models \varphi$  then  $\varphi \in \Gamma$ . The *closure* of a set of sentences  $\Gamma$  is  $\{\varphi : \Gamma \models \varphi\}$ .

We say that  $\Gamma$  is *axiomatized by* a set of sentences  $\Delta$  if  $\Gamma$  is the closure of  $\Delta$ .

We can think of an axiomatic theory as the set of sentences that is axiomatized by its set of axioms  $\Delta$ . In other words, when we have a first-order language which contains non-logical symbols for the primitives of the axiomatically developed science we wish to study, together with a set of sentences that express the fundamental laws of the science, we can think of the theory as represented by all the sentences in this language that are entailed by the axioms. This ranges from simple examples with only a single primitive and simple axioms, such as the theory of partial orders, to complex theories such as Newtonian mechanics.

The important logical facts that make this formal approach to the axiomatic method so important are the following. Suppose  $\Gamma$  is an axiom system for a theory, i.e., a set of sentences.

1. We can state precisely when an axiom system captures an intended class of structures. That is, if we are interested in a certain class of structures, we will successfully capture that class by an axiom system  $\Gamma$  iff the structures are exactly those  $\mathfrak{M}$  such that  $\mathfrak{M} \models \Gamma$ .
2. We may fail in this respect because there are  $\mathfrak{M}$  such that  $\mathfrak{M} \models \Gamma$ , but  $\mathfrak{M}$  is not one of the structures we intend. This may lead us to add axioms which are not true in  $\mathfrak{M}$ .
3. If we are successful at least in the respect that  $\Gamma$  is true in all the intended structures, then a sentence  $\varphi$  is true in all intended structures whenever  $\Gamma \models \varphi$ . Thus we can use logical tools (such as proof methods) to show that sentences are true in all intended structures simply by showing that they are entailed by the axioms.
4. Sometimes we don't have intended structures in mind, but instead start from the axioms themselves: we begin with some primitives that we

want to satisfy certain laws which we codify in an axiom system. One thing that we would like to verify right away is that the axioms do not contradict each other: if they do, there can be no concepts that obey these laws, and we have tried to set up an incoherent theory. We can verify that this doesn't happen by finding a model of  $\Gamma$ . And if there are models of our theory, we can use logical methods to investigate them, and we can also use logical methods to construct models.

5. The independence of the axioms is likewise an important question. It may happen that one of the axioms is actually a consequence of the others, and so is redundant. We can prove that an axiom  $\varphi$  in  $\Gamma$  is redundant by proving  $\Gamma \setminus \{\varphi\} \vDash \varphi$ . We can also prove that an axiom is not redundant by showing that  $(\Gamma \setminus \{\varphi\}) \cup \{\neg\varphi\}$  is satisfiable. For instance, this is how it was shown that the parallel postulate is independent of the other axioms of geometry.
6. Another important question is that of definability of concepts in a theory: The choice of the language determines what the models of a theory consists of. But not every aspect of a theory must be represented separately in its models. For instance, every ordering  $\leq$  determines a corresponding strict ordering  $<$ —given one, we can define the other. So it is not necessary that a model of a theory involving such an order must *also* contain the corresponding strict ordering. When is it the case, in general, that one relation can be defined in terms of others? When is it impossible to define a relation in terms of other (and hence must add it to the primitives of the language)?

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## Bibliography