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Fundamental situations in teaching biology: The case of parthenogenesis

Abstract

This theoretical paper considers the notion of fundamental situation in the sense of Brousseau's theory of didactical situations. It introduces some precise elements of this theory in which a teacher provides an environment for student work that aims to enable students, through constructive inquiry, to acquire well defined pieces of scientific knowledge. Situations become fundamental if they not only allow, but force students to construct the target knowledge. A classical example from mathematics is presented, where the target knowledge is a theorem of plane geometry presented as a puzzle. Then a new fundamental situation in biology is described for parthenogenetic reproduction, which has recently turned out to occur in Komodo dragons. An explicit demand to generate and test hypotheses that could explain the given example of dragon reproduction, using authentic DNA data, is given to students. The paper concludes with an analysis of the extent to which this fundamental situation in biology is authentic to the theory of didactical situations.

INTRODUCTION

There seems to be a consistent and growing awareness among science educators that the specificities of science content needs to be given a more systematic treatment in research studies (cf. e.g. Lijnse, 2000). To *focus* on the specifics of content to be learned and taught is, of course, not a new idea. It is the very rationale of the continental European tradition of *didactics* – in fact, similar variations of the Greek word are being used in almost every European language, although not so often in English, to designate the content focused study of teaching. This tradition can be traced back to the late 19th century (e.g. creation of chairs in mathematics and science education), but for a long time, it has remained somewhat naïve when it comes to the relationship between scientific knowledge (as produced and circulated in universities) and school science knowledge (as taught and learned in schools). More recently the notion of *didactical transposition* (Arsac & Chevallard & Martinand & Tiberghien, 1994; Brousseau, 1997; Chevallard, 1985; Verret, 1975) has been developed in mathematics and science education to articulate the complex epistemological processes involved in the genesis, anatomy and life of school disciplines, as bodies of knowledge to be taught and learned.

This *epistemological* perspective on different qualities and states of science knowledge is not merely descriptive. It has also contributed to the development of didactics as a *design science*. However, when we talk of didactical design – i.e. more or less precise designs for teaching a specific subject, which may be tested and documented – we immediately encounter the problem of *reproducibility*: to what extent may results obtained in one context be generalized to another? Which elements form part of the design to be tested, and which are merely auxiliary choices imposed by circumstances? Here the theory of didactical situations (to be described in more detail in the next section) is a promising framework. So far, this theory has mainly been developed in the context of mathematics teaching, but it is increasingly referred to in science education studies. A number of studies in physics education have used it quite explicitly (see eg. Tiberghien, 2000). The uses of the theory of didactical situations in studies of biology education are more rare (see however Clément, 1998, 64f).

The aim of this paper is to introduce some precise elements of this theory and then to show how they can be used to construct and analyze a design for teaching a very specific topic from biology. In the conclusion, we discuss briefly to what extent the notion of fundamental situation may be used as a model of design in other areas of biology.

FUNDAMENTAL SITUATIONS – SOME KEY CONCEPTS

The theory of didactical situations (TDS) was founded by the French mathematics educator, Guy Brousseau in the 70's, and since then, many colleagues have contributed to its refinement and applications within the field of didactics of mathematics (or, if you like, the epistemological program of research in mathematics education). It is by now a complex and thriving approach to both the analysis and design of mathematics teaching and learning situations and consequently, impossible to fully account for here. Brousseau (1997) presents a more complete exposition, although even this volume is a compilation of papers from different stages of the development of the theory, including some – but certainly not all – of the didactical designs around which the theory developed. Here we present only what is needed to grasp the idea of *fundamental situation*. In short, such a situation provides an environment (or *adidactical milieu*) for student work that aims to enable students to acquire a well defined piece of scientific knowledge – the *target knowledge*.

The milieu is adidactical because it surrounds the students with objects (material or immaterial) that they must work with autonomously. The situation becomes fundamental if this work does not only allow, but in a sense (made more precise in the next paragraph) *forces* the students to construct the target knowledge. Therefore, a fundamental situation is always fundamental for *some specific knowledge*. It is a widely held idea that the knowledge of an individual is constructed in particular contexts or *situations*; what is more controversial is the extent to which this knowledge may subsequently be freed (or abstracted) from the original situation, and transferred to other situations. It is a fact that 'official' scientific knowledge, as found in books and journals, often appears without any trace of the context or specific situation from which it was constructed. Although this may occasionally be traced more or less clearly by historians of science, the original situation is likely to be at best indicative of the milieu that a student needs to reconstruct, or *repersonalize* the knowledge for herself. The adidactical milieu, therefore, is constructed with the intention of letting a particular group of students learn the target knowledge. The construction must take into account what the students know and the obstacles they will face in progressing towards the target knowledge. It is, therefore, an artifact created with didactical intentions – not a natural environment of everyday experience.

Brousseau often uses the metaphor of *adidactical game* to describe the students' interaction with the milieu. As with any game, an *adidactical game* comes with rules that define it – and these need to be established both by the internal requirements of the milieu, as well as by explicit instructions from the teacher. These must *precede* the adidactical game – we say that the teacher *devolves* the milieu (or, the adidactical game) to the students. This phase is critical: the teacher must say enough for the students to be able to recognize the milieu and 'game' with it, but she must also be vigilant not to reveal her intentions (the target knowledge) directly, on pain of ruining or perverting the game. Thus, surrounding and conditioning an adidactical game, we have an interaction between the teacher and this game, called the *didactical game* because the teacher takes part in it, with specific didactical intentions. But during the adidactical game, she withdraws. The milieu must be sufficiently rich that the students will know when the game is won, or not. The students may ask for acknowledgement from the teacher once the game is won – but their certainty should come essentially from the response of the milieu, not from the teacher. And the whole situation is fundamental for the target knowledge if the didactical milieu contains sufficient information for the student to construct this knowledge and, moreover, this knowledge is the *only* winning strategy – imposed by the milieu but discovered, perhaps after considerable work, by the student. While one may say that a fundamental situation is "closed" in the sense of having a unique winning strategy, it may also be very challenging for the student, as we shall see.

A classical example, often referred to for its striking beauty and apparent simplicity, is the *puzzle situation*. The target knowledge is a basic fact (or, if you like, theorem) of plane geometry: two polygons P and Q are *similar* (essentially, have the same 'form') if and only if there is a positive number k such that the length of a side in P is k times the length of the corresponding side in Q. By subdividing polygons into triangles, one can see that this essentially is a fact about triangles; here, similarity of two triangles simply means that they have common angles. Now, what is needed to be convinced of this theorem? For most people, and certainly most children, it may not be a convincing and fulfilling experience to simply watch a teacher develop plane geometry axiomatically and eventually prove the theorem in question. More grossly, but certainly also closer to much of school reality, to be simply told it (in the form above or otherwise) is likely to result, depending on the external motivation, in a fragile memorization of the wording presented.

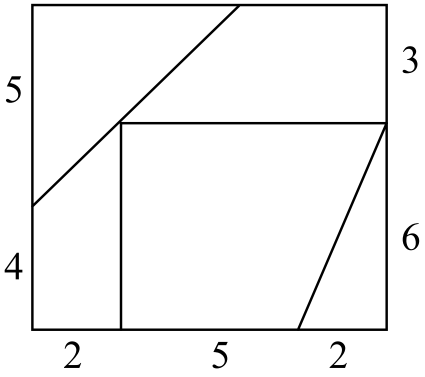


Figure 1. The puzzle situation. (cf. Brousseau, 1997, p. 177)

The puzzle situation – which can be considered fundamental for the knowledge indicated – presents the students with the following adidactical game: given pieces of a puzzle as shown in Fig. 1, enlarge the puzzle in such a way that sides measuring 4 cm in the original will measure 7 cm in the enlarged puzzle. Of course, the enlarged puzzle must still be a puzzle, in the sense that the pieces can be assembled as for the original. We pass here the intricate organization of students into groups which may enhance the actual game – as well as the false strategies which, empirically, arise with children at the age when such material is usually taught (cf. Brousseau, 1997, 177ff for these details). The main point is that the *only* way to win the game – that is, constructing a new puzzle fulfilling the requirements – is to construct the new pieces by multiplication of the sides (in this case, by the number 7/4).

Clearly, a fundamental situation may not be *unique*: the milieu, and the instructions devolving it to students, could be different. In the example, many other puzzles – simpler or more complicated, for instance – might do the job. One may then ask: what are the *essential elements* of the situation that are really needed for the target knowledge to remain the unique winning strategy – and what elements could be *varied* without destroying this crucial property. In a deeper analysis of the functioning of the milieu, the obstacles to be overcome by students must also be taken into consideration: what mistakes should remain possible, although clearly identifiable, in the students' game with the milieu? We say that we identify the *didactical variables* of the milieu in question as we specify the principal variations of the situation that would preserve its fundamental properties. Needless to say, even if there is a simplest possible milieu – in the example, one could argue this would be a square puzzle separated in two pieces by a diagonal – this may not, in practice be the best functioning. The point of looking for didactical variables is thus, rather, to analyze more deeply what is essential to develop the target knowledge – and to overcome certain associated obstacles – and what is merely accidental or could be chosen freely, e.g. according to the conditions of a particular context of teaching.

The problem of contingency (with respect to contexts, people, institutions…) seems almost inevitable in educational research. In particular, it can be discussed to what extent such research may have transfer value, in particular as regards to results based on experiments. And from this point of view, there are several attractive elements in the idea of fundamental situation:

- the almost logical necessity of learning, which in a sense can be 'proved' from the elements laid down in the adidactical milieu;
- the focus on the epistemological kernel, not of the target knowledge, but rather of the conditions for learning it (considered as core properties of the adidactical milieu);
- the specification of variables left open to be accommodated with more circumstantial features in an actual setting of teaching.

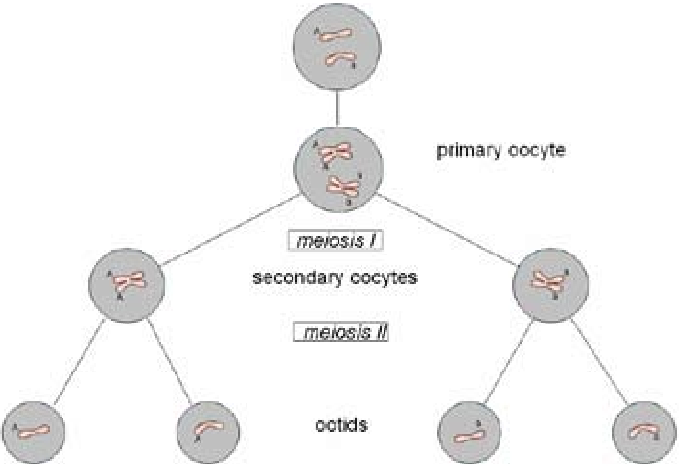
Not surprisingly, these features reveal the origin of TDS in the context of mathematics. This paper aims to discuss to what extent the ideas exposed above are meaningful in a science education context, even rather far from mathematics, namely in the context of teaching biology (specifically, the genetics and cytological mechanisms of reproduction). Concretely, we present and discuss a candidate for a *fundamental situation for parthenogenesis*. But before that, we provide some remarks on what could be expected in general, just given the most obvious differences between mathematics and any empirical science.

The (natural) sciences, from physics to natural geography, refer more or less directly – and more or less through models – to some part of material reality. The objects studied by the sciences are, of course, not simply material; theoretical models are also important elements. But the validity of their results depends ultimately on the ability to describe, explain, control or predict material phenomena. To what extent the ontological divide between, say physics and pure mathematics, is absolute, is certainly a controversial issue in philosophy, and we do not intend to treat it here. However, from a more pragmatic viewpoint, we observe that an adidactical milieu will always have material parts, whether they are just semiotic signifiers, or include more tangible objects like pieces of a puzzle. And the challenge in constructing a fundamental situation in mathematics is in part linked to the need to develop this material part of the adidactical milieu in a form that is accessible for prospective learners. One point of the puzzle situation is to embed the necessity of a geometric principle in the (material) constraints of enlarging concrete pieces of carton, to support it by tangible experience.

By contrast, the challenge in establishing a fundamental situation for a natural scientific principle, may not so much be to cook up a material environment but rather to choose one which is neither too complex (potentially leading to an explosion of hypotheses, unrelated to the target knowledge) or too narrow (not really allowing for an adidactical game). Moreover, in many simple, familiar contexts, students may have a number of preconceptions which may both represent obstacles and vehicles for the target knowledge. Indeed, many of the objects that one could bring into the classroom – as part of an adidactical milieu – would be chosen because of their potential to activate the students' experience and knowledge as resources for generating hypotheses and new knowledge. However, such preconceptions may also act as obstacles to the target knowledge which could be difficult to foresee and therefore to control.

The situation: a mystery about dragons

We now present a problem in roughly the form one could devolve it to advanced secondary level students with a reasonable background knowledge of genetics including the phenomena of mitosis and meiosis. This situation is essentially based on information published by Watts et al. (2006), cf. also Dawkins (2006). A graphic representation of meiosis (see Figure 2) as well as photographs of a mature Komodo dragon and a hatchling, should accompany the explanation below.



Drawn from Suomalainen, E., Saura, A. & Lokki, J. (1987). *Cytology and Evolution in Parthenogenesis*. CRC Press: Boca Raton, FL p. 115.

Figure 2. Meiosis in a female with one homologous set of chromosomes resulting in four eggs.

> Komodo dragons (Varanus komodoensis) are the largest monitor lizards in the world, weighing up to 90kg and growing as long as 3m. Because they are large and predatory, they are even known to eat the occasional human. There are only 4000 estimated to still live on the three Indonesian islands where they are found. Because of this small number, they are in danger of extinction.
> In December of 2006, Flora, a female Komodo dragon at Chester Zoo in the United Kingdom laid a clutch of eggs, some of which hatched into healthy offspring. Normally, this wouldn't be a noteworthy event, except Flora had not been kept with any male dragons, so how her eggs were able to develop is a challenging question. It could be useful to understand the mechanism behind the

hatching of these eggs, presumably without fertilization by a male, as it might be important in helping insure the survival of the dragon population. A recent article (in the journal Nature) discusses how Flora could have produced these fertile eggs, but so far scientists don't know for certain how it happened. Here is what is known by scientists:

Altogether, Flora laid eleven eggs, eight of which hatched to produce healthy male offspring. The other three embryos, which were also males, died before hatching. Earlier in April of 2006, at London Zoo, another UK zoo, Sungai, who is also a Komodo dragon, had a clutch of four eggs hatch which were also all males. It had been two years since her last known contact with a male. Later, Sungai was mated with Raja, a male dragon, and produced a mixed group of babies, some of whom were male and others who were female. DNA analysis of the eggs from each of the clutches and of the adults was done to see what their genotypes were. Table 1 shows the results for all of the adults (Flora, Raja and Sungai) and typical eggs from each clutch. The two allelic genes for seven different chromosome places (K03 to K10) are compared. It's also interesting to note that whereas in humans the sex-chromosomes are labelled as 'X' and 'Y', in dragons they are labelled 'W' and 'Z'.

Based on what you have learned about meiosis in humans (see attached page to review this) and what is known about these dragon egg hatchings, figure out a plausible way in which clutches 1 and 2 could not have had a father. Be consistent with what you know about mitosis and meiosis in vertebrate animals. Make a drawing of your ideas about this (or just label and draw on the human meiosis review page). [Hint: you can use the data in Table 1 to see if the babies were clones of the mother and whether the alleles for each genotype are the same or different.]

Once you have come up with a hypothesis which explains it all, tell why this might have been a good survival 'strategy' for these dragons during the past millions of years their species has lived and why this strategy may be helpful again today as they near extinction.

Table 1: Genotypic Data for three Komodo Dragons and their offspring (adapted from Watts, et. al., 2006, Supplementary Table 1).

	Clutch	Animal	Sex	Genotypic Data (base pairs of alleles) for Flora, Sungai, Raja and Three Clutches of Eggs													
				K03		K05		K06		K07		K08		K09		K10	
Chester Zoo		Flora	♀	134	136	198	201	133	133	211	216	151	154	188	200	164	164
	1	Egg 1	♂	134	134	198	198	133	133	216	216	154	154	188	188	164	164
		Egg 2	♂	136	136	198	198	133	133	216	216	151	151	200	200	164	164
		Egg 3	♂	134	134	201	201	133	133	211	211	154	154	188	188	164	164
		Raja	♂	134	136	198	198	141	141	211	216	151	154	188	206	164	166
London Zoo		Sungai	♀	134	136	198	198	137	141	211	213	154	154	190	190	166	166
	2	Egg 1	♂	134	134	198	198	137	137	211	211	154	154	190	190	166	166
		Egg 2	♂	134	134	198	198	141	141	211	211	154	154	190	190	166	166
		Egg 3	♂	136	136	198	198	137	137	213	213	154	154	190	190	166	166
		Egg 4	♂	136	136	198	198	141	141	213	213	154	154	190	190	166	166
	3	Egg 1	♀	134	134	198	198	141	141	211	216	154	154	190	206	164	166

This situation is meant for use in class where the students could then be assigned to work individually or in groups. The teacher should then refrain from evaluating hypotheses of students immediately, and instead organize, after the adidactial game, a class discussion based on students' arguments (cf. the next section).

A FIRST ANALYSIS OF THE SITUATION

The *target knowledge* of the situation is the possibility – if not necessity, in this case – of a form of reproduction used occasionally by some vertebrate species: *parthenogenesis*. In the case of Komodo dragons, this means that a viable egg is created from one unfertilized ootid, which probably fuses with another unfertilized ootid to form a zygote with a complete set of chromosomes, which can then grow by the usual cell division of mitosis into a complete organism (see Figure 4 for how this probably occurs in Komodo Dragons). The result of meiosis II is that each ootid has the typical distribution of one of each pair of chromosomes, one set of the mother's genetic alleles. Upon fusion with another ootid to form a zygote, a second set of the mother's genetic alleles are added which returns the cell to the full diploid number of chromosomes. However, while all of these alleles are from the mother, each zygote will have a different combination of the mother's genetic alleles. Consequently, just as different eggs when fertilized in sexual reproduction produce babies with genetic differences, the offspring here would not be *identical* (as they would be if arising from cloning), due to the random distribution of the unpaired chromosomes to the eggs (*meiosis*). So, for example, in Figure 4, the zygote could have been 'aa' rather than 'AA' but not 'Aa' since terminal fusion is normally between two ootids from the same secondary oocyte. In Komodo dragons, cytological studies have not yet been done and thus, terminal fusion is just a strong hypothesis since the offspring are not clones of the mother, as might be the case with other kinds of parthenogenesis (Groot *et al*, 2003 and Suomalainen *et al*, 1987).

In the same general way that parthenogenic offspring are homozygous for most genes, they will, in the case of Komodo dragons, all be males (see Figure 2), since unlike in humans, male dragons have a matched pair of sex chromosomes (ZZ) and females have an unmatched set (WZ). Hence since they are all males, the offspring may not reproduce sexually among each other (but possibly could with the mother). The production of only male offspring further strengthens the assumption that parthenogenesis by terminal fusion is the means by which this reproduction has occurred, since other forms would have produced either only females or both genders (Groot, *et al*, 2003).

As this short discussion suggests, a reasonable understanding of parthenogenesis and its effects involves a number of notions which are basic even for explaining the mechanisms of normal (sexual) reproduction. From a didactic viewpoint, this offers the advantage of reinforcement or even correction of existing knowledge (misconceptions) built at earlier stages, while adapting it to the new situation. The situation presented in the previous section is meant to lead to some elements of the above discussion, but naturally these elements cannot be expected to arise from it in the order and form just given. The milieu presents the student with concrete and surprising events related to Komodo dragons. It also contains an explicit demand to generate and test *hypotheses* that could explain these events while being consistent with all of the information. This dialectic game of generating and testing hypotheses will depend both on the milieu and on the students, in particular on how they are activate their existing knowledge in the milieu.

We now present some hypotheses which we find likely to occur in this game, along with comments (in most cases, refutations) that arise fairly directly from the given information.

Hypothesis 1: Flora and Sungai could have mated with males from another closely related reptile species.

Refutation: Even assuming that such a mating had been possible, the odds of a mate from another species having allelic genes at the same exact places on the chromosomes are very low. So, all of the alleles would not have been the same, as they clearly are in Table 1.

Hypothesis 2: Flora and Sungai may have stored sperm from a mating with Komodo males years before they were isolated from males in their zoos and used those sperm cells for mating.

Refutation: While reptiles are known to store sperm, in this case this idea also violates the DNA data from Table 1 since all of the eggs, but none of the adults, have identical pairs of genes. The chances of this happening if a male had contributed one of each base pair are extremely small.

Hypothesis 3: Each baby may have grown just from a single egg of the mother without that egg having been fertilized and without duplication of the half-number of chromosomes found in all such gametes. In other words, a sex cell of these female dragons could grow the same way as a zygote grows, by normal mitotic cell division.

Refutation: According to Table 1, the babies had two genes at each point on their chromosomes. Since an egg only has one set of chromosomes with one set of genes (cf. meiosis review sheet) this cannot be a correct explanation.

Hypothesis 4: How about if two *different* eggs from a mother got together to form a zygote, then, the zygote would have only the genes of the mother, but they would vary from other zygotes depending on which two eggs of the mother formed the zygote, as they do in Table 1.

Refutation: This would explain that the offspring are not clones of the mother, due to the genetic variation of the eggs. But if a combination of genetically different eggs fused, the result would not result in eggs with the same two genes for each place on the chromosomes (cf. Table 1).

Hypothesis 5: Then, the zygotes must each have formed from the fusion of two eggs (ootids) arising from one secondary egg (secondary oocyte) (see Figure 4) and the result would in fact be genetically identical to this secondary egg. These certainly have identical pairs of genes at each place, and they arise in many different forms.

Comment: This would indeed explain the genetic similarities and differences of the offspring, but not the fact that they were all males. Wouldn't females produce just eggs with single chromosomes for the female phenotype?

Hypothesis 6: According to the given facts and the above hypothesis, this would indeed be the case if females were ZZ. They could never produce ZW in this way. So, to get only males, the only possible explanation is that in Komodo dragons, males have two of the same sex chromosomes (WW or ZZ) and females have one of each (WZ), unlike for humans. Then, the zygotes arising from a fusion of two ootids would be ZZ or WW, and the latter would not be viable just as YY is not viable in humans. WZ zygotes are not ever produced since the ootids that fuse both come from the same secondary oocytes which carry both Z or both W.

Comment: Exactly. Now, how about the last question about why this might way of reproducing might be a good survival strategy?

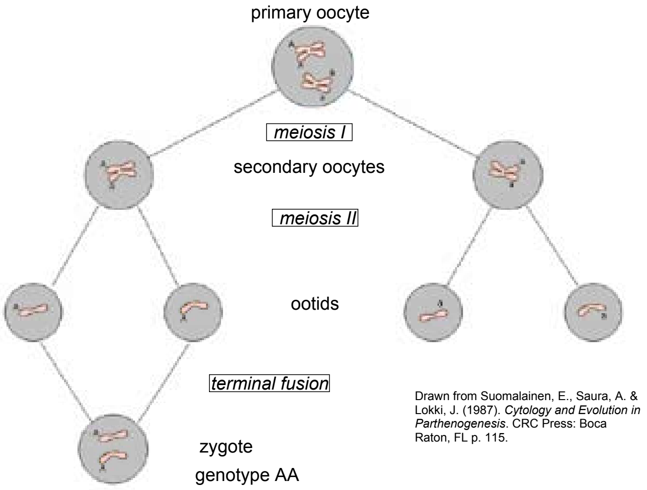
Hypothesis 7: This form of reproduction may simply be a genetic feature of an odd minority of female dragons, whereas most only reproduce normally. This minority would then be able to reproduce even in the absence of males.

Refutation: But we know that Sungai reproduced in both ways – and reproduced sexually when this became possible due to the presence of a male. Table 1 shows that Raja and Sungai are the parents of the third clutch (clutch 3 shown in the table).

Hypothesis 8: OK, so it looks like perhaps these dragons can all reproduce either way. This form of reproduction occurs only under special conditions, namely prolonged separations from male dragons, and could conceivably be an ‘emergency option’ which allows for one single female dragon to perpetuate the species (since subsequently she could reproduce sexually with her male offspring).

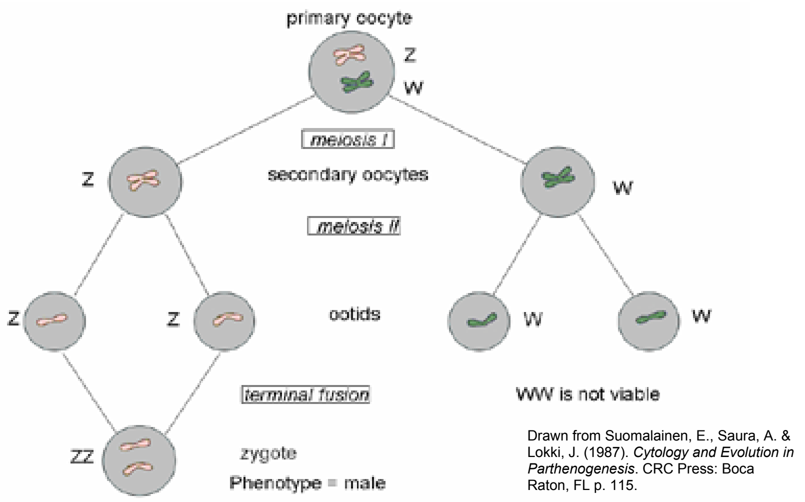
Comment: Correct. In fact, such an option may indeed facilitate the colonization of new Indonesian islands, even if just one female managed to arrive there since she could eventually mate with her male offspring.

All in all, this resolves all issues and scientific evidence suggests this is the best hypothesis. Drawn out, it would look something like Figures 3 and 4 and is called parthenogenesis.



Drawn from Suomalainen, E., Saura, A. & Lokki, J. (1987). *Cytology and Evolution in Parthenogenesis*. CRC Press: Boca Raton, FL p. 115.

Figure 3. Terminal fusion parthenogenesis of one pair of autosomes in Komodo dragons showing the production of a zygote.



Drawn from Suomalainen, E., Saura, A. & Lokki, J. (1987). *Cytology and Evolution in Parthenogenesis*. CRC Press: Boca Raton, FL p. 115.

Figure 4. Terminal fusion parthenogenesis of the sex chromosomes in Komodo dragons which results in only male (ZZ) offspring.

A FUNDAMENTAL SITUATION?

Recall that to say that a didactical situation is *fundamental* for the target knowledge is to say that the target knowledge is the *only* wining strategy in the adidactical game(s) contained in the situation. We now discuss in what sense the situation described in Sec.2 really is a fundamental situation.

In this case the target knowledge, explained in detail at the beginning of the previous section, can be summarized by the following two points:

l. Female Komodo dragons may reproduce, in the absence of males, by the process of fusion of pairs of eggs arising from the same secondary egg, as this may result in a viable zygote.
ll. The sexual genotype of *female* dragons is WZ, while males are ZZ (i.e. they are unlike humans where males carry the different sex chromosomes).

This must be deduced based on general knowledge of mitosis and meiosis combined with the given information in the given situation. All of this information may be simplified to the following points (where, in particular, C, D and G represent an extraction of the relevant information from Table 1):

A. Flora and Sungai both reproduced without mating (resulting in a total of 12 babies).
B. The babies arising from A. were all male.
C. The babies arising from A. were homozygous at all loci
D. The babies arising from A. were different from each other (and from their mother)
E. Sungai later reproduced normally by mating with a male.
F. Some of the babies arising from E. were female, and some were male.
G. The DNA analysis of one baby arising from E. shows that it was not homozygous at all loci.

Of course, the problem of the situation is essentially to explain A., while the rest of the information is provided to let the student do so. Together, A-G form the essential parts of the adidactical milieu. Most of the remaining information – like the fact that the dragons lived in UK zoos – must somehow be put in the background, as it is not directly relevant to the question. Of course, this already constitutes a difficult and important step towards a solution.

Not all of the distilled information is equally important to solve the 'mystery'. In particular, the affirmations E.-G. are auxiliary: they simply say that normal sexual reproduction may occur with female dragons that reproduced in the mysterious way described by A.-D. The crucial information in order to find out how this must have happened is contained in C. and D.: the zygotes from which the babies of clutch 1 and 2 have grown must be identical to the secondary oocytes which are the *only* items in Figure 2 which carry one complete set of *identical* chromosome pairs (while still being different from each other and from the chromosomes of the mother). If ootids were formed normally by *division* of these secondary oocytes, they *must* have fused again – or, as an admissible alternative, some secondary oocytes did *not* divide but began to multiply through mitosis. We cannot decide between these alternatives from the given information, but the basic result is the same: C. and D. can only be explained from the hypothesis of zygotes identical to secondary oocytes. We have thus arrived at target knowledge I., or else the variant that secondary ootids may begin to multiply through mitosis (without dividing into ootids), in the absence of males.

With this hypothesis, the zygotes giving rise to the babies have sex chromosomes of type ZZ or WW; it is therefore immediately clear that they must be all of the same sex, and according to B., this is the *male* variety. Thus, dragon males are ZZ or WW. We cannot say which, but this is a question of mere notation; we may thus assume that males are ZZ. Females would then have to be ZW, since only then could the combination ZZ arise in secondary oocytes through meiosis. And then, as only two sex varieties (ZW and ZZ) arise with normal sexual reproduction, we must conclude that WW is not viable so that, statistically, half of the zygotes arising from the derived process do not develop through mitosis into viable eggs. This is target knowledge II.

In conclusion, the given information essentially forces upon us the mechanisms of parthenogenesis, except that we cannot conclude if normal ootids are formed before and perhaps along with parthenogenetic zygotes, or if – in the absence of males – it is possible that secondary ootids begin mitosis without first dividing. So, with the possible exception of this detail, the essential mechanisms of parthenogenesis and sexual coding of Komodo dragons come out naturally and necessarily from the given information. This means that the information A.-G., together with general knowledge of reproduction mechanisms at the cell level, form the core of a fundamental situation for I. and II. We write "the core" because the actual presentation of the information and the task may be varied. We discuss this in the next section.

DIDACTICAL VARIABLES OF THE SITUATION

Didactical situations do not live in a vacuum. The basic principles of genetic reproduction (in particular in humans) are part of the secondary curriculum in most countries. Substantial work on this is required as a prerequisite for the situation, in order for students to appreciate the dilemma caused by the unfertilized, yet diploid eggs in the Komodo dragon. In particular students should know that male and female haploid gametes normally unite in fertilization to produce viable offspring.

On the other hand parthenogenesis may not itself be a mandatory element in the curriculum – even if this is a normal form of reproduction in some (mainly invertebrate) animal species. But even in this case the situation in question may be useful to consolidate and challenge students' knowledge of the processes of meiosis and sexual reproduction. It would also force them to reconstruct their understanding to include parthenogenesis and an alternative method of reproduction and of sex determination.

Indeed, how to use and adapt the fundamental situation presented above depends crucially on circumstances which cannot be foreseen in a theoretical analysis like the present one. The difference between a concrete devolution of the adidactical milieu suggested in the situation, and the 'bare essentials' extracted in the section *A fundamental situation*, is just that: the essential information (A.-G.) must be kept to ensure a fundamental situation for the target knowledge I.-II., but the actual milieu could be varied according to the needs and preferences of teachers and students in a given class. In this section, we discuss some of the principal variations of the milieu described in the dragon situation, as an illustration of the concept of didactical variable introduced earlier .

The first and most radical type of variation is to *split the adidactical situation* into two or more parts, based on the observation that the target knowledge splits into two parts which are derived from partially independent parts of the core information A.-G. Indeed, I. is deduced from A., C. and D. (with E. and G. helping to explain the conditions leading to I.) while II is deduced from B. (while F. confirms that normal reproduction remains possible in the presence of a male). So, after studying meiosis, a first fundamental situation for I. could be based on A., C., D., E. and G. Then, after summing up this achievement, and devolution of a new milieu adding the information contained in B. and F., learners could construct the target knowledge II. of ZW/ZZ sex determination. For learners without much experience or capability at considering several variables simultaneously, this approach would reduce the difficulty of the problem, while resulting in similar learning outcomes.

For more capable and experienced students, the additional difficulty of considering both issues simultaneously is potentially more challenging, closer to scientific reality and consequently more rewarding and authentic. In any case, if they are separated, the parthenogenesis situation should precede that of sex determination, since the latter requires knowledge of how the egg was formed.

A middle way might also be considered: different groups of students in the same classroom could be given either the parthenogenesis dilemma (first milieu above) or a sex determination scenario (based on A., B., E. and F.), and be allowed to work independently towards possible hypotheses. This resembles the puzzle situation in the sense that students are given different 'pieces' of the total problem. Then, at the right moment, the teacher should combine teams from each problem and challenge them to consider each other's hypotheses to resolve both dilemmas. Each group will have considered information separately, but only when their ideas are put together with those of the other group will both targets of knowledge be attained.

We have summed up the three main options for this first variable in Table 2. We now proceed to consider variations where the first option has been taken, that is, to more subtle variations of the situation. These concern essentially how the data is presented.

Table 2. A comparison of three possible didactical milieus for the fundamental situation.

Adidactical milieu(s)	**Target group**	**Didactical features**
Simultaneous Parthenogenesis **and** Sex determination (elements A-G)	Older or more formal thinking students	Challenge and realism, corresponding to reward and authenticity; but some risk of unproductive 'guessing games'
Sequential Parthenogenesis (elements ACD(+EG) **then later** Sex determination (elements B(+F))	Younger or less formal thinking students	Students may repersonalize the target knowledge in two manageable steps, and consequently, the game is more likely to succeed. But it is less realistic.
Synergistic Group **Either** Parthenogenesis (elements ACD(+EFG)) **or** Sex determination (elements B(+EFG))	Students capable of cooperative hypothetical deductive thinking	Students depend upon both the cooperative thinking of their own group as well as that of other groups to achieve problem resolution.

One key variable is *the use and role of the table* (Table 1) as a part of the adidactical milieu. It certainly adds authenticity to the situation as it is based on real data, and is more demanding than a more direct presentation of the information in C. If one decides to use such data, one should be careful to ensure it is accessible to students. They might have seen similar data for instance in the context of human DNA-tests; or alternatively a more detailed explanation of the meaning of the table could be provided. One could even consider giving the table a more prominent position, and leaving out some of the auxiliary information (e.g. just noting that both females were known to be able to reproduce normally) to focus on the genetic data.

Table 1, if present, forms part of the material milieu in which the target knowledge must be derived from raw allelic information. Another key element of the material milieu – which we consider an important didactical variable for the situation – is the *representations of meiosis* available to students (a review sheet as suggested could be more or less suggestive, as could be the representation otherwise available to students, e.g. in their text book). In this case, one needs only consider what happens to one pair of chromosomes in this process, and in fact one must focus on the information in C. and the presence of two identical ootids – neatly linked to the corresponding secondary oocyte in Figure 2. The possibility of student's imagining an unusual sequence of Meiosis II to generate a zygote identical to the secondary oocyte (in the viable case ZZ) could depend crucially on how suggestively this information is represented. Likewise, depending on the representation of meiosis available to students, other ideas might come up, such as premeiotic doubling that would result in diploid ootids; however they would be identical clones of the mother (cf. Groot *et al*, 2003) and hence this would not be an acceptable solution here.

Some phenomena that are of importance in other contexts – as the occasional DNA exchange of homologue sections during Meiosis I – could profitably be left out as it is not essential for this situation. However, a too schematic representation may, despite its purity, not be the most useful if the target is to make students relate to (and extend) their previous knowledge of meiosis to encompass parthenogenesis. If a review sheet (such as Figure 2) is deemed necessary, it could be useful to make it similar to representations of meiosis which have been used in first encounters, even if it is simplified (e.g. to show just one pair of chromosomes and leaving out DNA exchange).

The *reference to scientific background and practice* is another didactical variable. How much should be said about the challenges of the specific case, the research and researchers involved, and the species of Komodo dragons? On the one hand, it is important that the case appears to students as a challenging and as a recent challenge for researchers, with a solution that is deduced from pertinent data and careful analysis. On the other hand much of the detail that could interest the expert will be confusing and useless for students.

More generally, any adidactical milieu, however faithfully meant to reproduce 'reality', will be just that: a reproduction, an artifice constructed with didactic intentions and adapted to the students who must play with it. In some cases, students may experience directly the biological phenomena under consideration; this cannot be the case for the study of Komodo dragons over a prolonged period of time. Details provided which do not correspond to key information (A.-G.) may still be needed to create a meaningful situation. For instance, there is no formal necessity to know that the animals were observed in British zoos, or what the names of the dragons were etc., as long as A. comes out clearly.

To sum up, the analysis in the section, *A fundamental situation?*, shows the *essential features* that make the situation described a fundamental situation for the target knowledge. It also implicitly shows the potential for didactically motivated variation that remains – and at least one option for a more substantial change in the situation. Empirical tests of the Komodo dragon activity should be conducted to determine the extent to which actual profiles of student problem solving behaviors, including the generating and testing of hypotheses, corresponds to the nine hypotheses that were proposed above. What we have presented here is a *theoretical* validation of the situation as fundamental for the target knowledge. An empirical validation in a given context would obviously consist in showing that students are seen to be actually constructing the target knowledge from the adidactical milieu. For this, we have so far only informal evidence.

CONCLUSIONS

The approach to biology teaching suggested here was illustrated by one particular example which may, due to the combinatory phenomena in genetics, find some readers wondering if this would mainly work for some more or less mathematized aspects of life science. In other words, to what extent could similar analyses be conducted in other sections of the life science curriculum, such as the qualitative categories used to classify species in natural history? Certainly more traditionally descriptive biological venues might seem to lend themselves less readily to the hypothesis of fundamental situations as a strategy for didactical design. However, the current state of work in, for example the classification of organisms, is based to such a large extent on genetic and biochemical comparisons, that the recreation of fundamental situations for main principles may be quite feasible. Notice that the construction of such situations require a solid command not only of the target knowledge but also of the scientific processes and strategies behind it, as well as a careful adaptation to the students that are meant to repersonalize it.

In virtually every aspect of contemporary biological research, knowledge production is intimately linked to deductive inference from observations, and as in the example this could serve to create the necessary resistance in an adidactical milieu. In ecology, for example, students could be challenged to find the non-intuitive equilibrium point in a disturbed ecosystem, when given selected elements of the system and dynamic energy flow data about those elements. Students of biomechanics could immerse themselves in a milieu of forces, muscle contraction limits and repetitive calisthenics to determine why a given exercise plan is failing to increase muscle mass. In each of these instances, the 'logical necessity' to resolve either the point of equilibrium in the disturbed ecosystem or the ineffective exercise routine, would drive the learner towards the target knowledge. The rich but arranged arena of biological data and phenomena given in each case would provide the conditions for learning. And, as in mathematics, the challenges of a well-constructed fundamental situation can leave the learner with much more than the target knowledge.

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