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„Video games in the Biology classroom –
Game concept for a pollination game with evolutionary back-ground“

verfasst von / submitted by
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Abstract

Video games have successfully entered the classroom and can be considered a new learning tool. However, developing a good video game with the advantageous properties of COTS games and educational games is challenging. This diploma thesis examines which elements a video game on pollination biology must include to facilitate concrete learning and conceptual understanding, without neglecting the entertainment aspect. This interdisciplinary endeavour includes the theory of pollination biology, subject didactics, game studies and game design. By studying meta-analyses about the use of video games in educational settings, as well as finding and analysing tabletop and video games with focus on biology and also pollination, a video game concept suitable to complement teaching pollination biology in Austrian secondary school was developed.

Zusammenfassung

Videospiele haben sich in den letzten Jahren erfolgreich im Unterricht und als Lehr,- und Lernmethode etabliert. Allerdings ist es schwierig ein gutes Videospiel zu entwickeln und umzusetzen, welches die Vorteile von kommerziellen und Lernspielen vereint. Diese Diplomarbeit untersucht, welche Elemente in einem Videospiel vorhanden sein müssen, damit konkretes Lernen und zusammenhängendes Verständnis vermittelt wird, ohne den spielerischen Aspekt zu vernachlässigen. Dieses interdisziplinäres Unterfangen vereint Theorien von Blütenökologie, Fachdidaktik, Ludologie und Spieldesign. Durch die Erkenntnisse aus Metaanalysen zum Einsatz von Videospielen im Bildungsbereich, sowie der Analyse von Brett- und Videospielen mit Fokus auf biologische Themen wurde ein Spielkonzept entwickelt, welches geeignet ist um Blütenbiologie ergänzend zum Regulärunterricht in der Unterstufe in Österreich zu unterrichten.

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1. Introduction

Video games have a rather controversial reputation, which has persisted for quite a long time, especially when it comes to the genre of shooter games which has been widely criticised in the media, stoking fear and establishing an overgeneralized opinion of video games. However, during the last decade, the bad reputation has changed, and a new movement started, led by educators, researchers and game developers alike, who have been interested in the positive effects of video games in connection with motivation and learning. The Anglo-American countries not only began, but continue to advance in this research, while German speaking countries catch up. In Vienna, the first Austrian games trade fair was held in September 2017, bringing together national developers, educational institutes and most importantly, gamers. With over 3000 visitors[1] the event was a success, providing a platform to exchange ideas and discuss prospects. Nowadays, much is on the move already, given that tertiary educational facilities throughout the country offer educational opportunities tailored to the games industry's needs.

"Why video games?", some may ask. The impact of video games should not be neglected. A study shows that 4,9 million Austrians play video games regularly, of which women constitute nearly 47%. Their average age of 35 shows that not only children playing video games, but adults play as well[2]. Although, the time spent playing video games is often criticised as a waste-of-time, researchers point towards their potential as learning tools in general and in science education (National Research Council (U.S.), Honey, Hilton, & National Academies Press (U.S.), 2011, p. 2). Instead of condemning games and their players, their potential should be realized and time and resources to study them adequately should be invested. The same holds true for their implementation in schools and curricula. Research from the Anglo-American sphere (National Research Council (U.S.) et al., 2011, p. 2) suggests their use especially in science classes. For once, it is often noted that in science, students struggle with the visualization and general understanding of scientific phenomena and concepts. Here, video games may support and aid learning and understanding. Furthermore, many of these concepts and phenomena require repetition to fully grasp the underlying functions and components, which may be granted via video games (Clark, Nelson, Sengupta, & D'Angelo, 2009, p. 2).

In Austria, a focus of biology didactics research is plant pollination, as it seems to be a rather complex topic (Lampert, 2012, p. 129). With the emergence of game studies, more sub-disciplines have followed, and the process of game design, development and testing has been examined scientifically. Among these disciplines are also the study of serious games and educational simulations, digital-game-based learning and many others, with the objective to study the relation of games and learning more closely.

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[1] https://playaustria.com/en/fair-info/ (16.05.2018)

[2] https://derstandard.at/2000065784515/4-9-Millionen-Oesterreicher-und-Oesterreicherinnen-spielen-Videospiele (16.05.2018)

My personal interest in the topic "learning and games" started in 2015 during a university course which focused on "Digital games, simulation and virtual worlds for teaching and learning", held by Mag. Alexander Schmölz and Dr. Chris Walsh. The goal was to develop a board, card or digital game for a school, to trigger a discussion about serious topics with the students. The final versions were digital games, designed and developed by small student teams and piloted in a Viennese lower secondary school (NMS). Furthermore, all games took part in the Samsung mLearning competition and one game, Stop the Mob (2016), a game about bullying, even won the first prize. My team consisted of three students and together with the technological support from a game developer, Johannes Scharl, we created Pack me!- The packaging game (2016), for which we were also awarded at the Samsung mLearning competition. The goal was to draw the player's attention to different packaging materials and show the ones which are more harmful to the environment than others. A product database from Greenpeace's marktcheck.at served as a basis.

Since then I am confident that learning via video games could be a new and innovative form of teaching worth studying more closely, which is why I am dedicated to this field. As a gamer myself I, however, discovered quickly that pure serious games or "learning games" have a rather unpopular name and that an effective game would also have to make fun. Balancing the entertainment and learning aspect is surely the most difficult part during the game design process.

This thesis tries to shed light on the insights gained concerning the use of video games in science education and, furthermore, it shows that biological content (pollination biology) can be integrated in a video game concept. It combines all four disciplines: Pollination biology, subject didactics, game studies and game design principles. It is the first diploma thesis on the subject specific pedagogy institute for science of the University of Vienna about the use of video games in science education, and therefore explains the theory in a larger context before narrowing it down to the essential information. The result of this study is a game design concept for a video game on pollination, suitable for students of lower secondary school, which learn about pollination biology but also tries to capture older pupil's attention by integrating fun elements and not prioritize the educational aspect too much over the entertainment factor.

This thesis will be structured as follows: Chapter 2 will introduce the research question and research framework. This is followed by chapter 3, which will focus on the theoretical background of pollination biology, pollination didactics, game studies, video game studies and serious games. Chapter 4 will continue with the principles of game design followed by chapter 5 with an elaboration of the process of developing the game concept for the pollination game and the description of the design method applied for the prototype, starting with game-based learning best practises, introduction to biology related game and video games, and most importantly, a state-of-the-art analysis of video games on pollination. Finally,

chapter 6 will then present the result, the game design document for a pollination game which will be followed by chapter 7, a discussion of the limitations and possible outlook for further research on the topic.

2. Research question, goal and method

This thesis sheds light on the potential usage of video games in the Biology classroom, its benefits, limitations and drawbacks. As a result, a game concept in the form of a prototype for a pollination game will be presented. As there have not been many studies conducted in German speaking countries with the specific focus on games for Biology, most arguments will be drawn from Anglo-American research. Video game studies itself is an interdisciplinary field, and with the special focus on serious games for teaching and learning even more disciplines are involved, whose perspectives must be considered. Based on the literature, the following research question concerning pollination biology didactics and serious game design is proposed:

Which features must be implemented in a video game concept on pollination biology to facilitate concise and concrete learning?

Answering this question involves game design and learning principles, which combined, facilitate learning. To find an answer for the research question and to come up with a suitable game concept, several work stages are involved, which are summarized below:

1. Familiarizing with the biological background of flower ecology
2. Reading up on the recent research on teaching flower ecology in Biology classes in Austria
3. Reading up on science learning principles and learning science with video games
4. Providing an overview of game studies and the development of serious games
5. Summing up the basic principles of game design, including “serious” game design
6. Analysing existing video games depicting pollination
7. Coming up with a game concept and writing a game design document
8. Drawing final conclusions

3. Theoretical introduction

This chapter presents the theoretical basis for this thesis, starting with the biological part with an explanation of pollination biology, especially those aspects relevant to the game concept. Connected to pollination biology is the latest research regarding teaching pollination in school, the difficulty of the topic including student's misconceptions.

3.1. Pollination Biology

This section will define the term flower in contrast to blossom and briefly introduce the basic elements of a hermaphrodite flower. Furthermore, pollination in contrast to insemination is elucidated and several pollination and pollinator syndromes listed. This content knowledge represents the basis of the game, and therefore a thorough description is necessary.

3.1.1. Blossom and flower

Analogous to German, where "Blume" and "Blüte" are often used interchangeably, although both terms have different meanings from a botanist point of view, the English language too does not distinguish well between the terms "blossom" and "flower", and "flower" translates to both German "Blume" and "Blüte". Flower is the English equivalent to German "Blüte", the clinched end of a sprout, whose leaf organs are in direct or indirect relation with sexual reproduction (Heß, 2005, p. 83). Their sterile parts often come in different colours and shapes, and attract pollinators and protect the reproductive parts. Blossom, on the other hand, usually refers to the flowers of fruit bearing trees that flourish in spring (i.e. cherry blossoms). Blossom is, however, not the translation for German "Blume". "Blume" is the pollination entity of spermatophytes, and it serves an ecological-functional purpose of attracting pollinators.

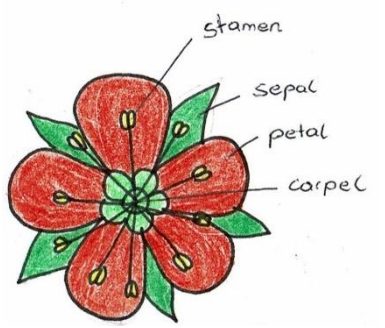

Figure 1: Hermaphrodite flower plan view, (adapted from Heß, 2005, p.84)

There are three types of flowers: meranthium, euanthium and pseudanthium. If the pollination entity of spermatophyte only represents one part of the morphological entity of the flower, it is called meranthium (and in German "Teilblume" as well). The meranthium is characterized by many single flowers ("Einzelblumen") which make up the whole flower ("Blüte"). The euanthium is the typical single flower, where one flower equals one "Blume". The last form is the pseudanthium, or "false flower", where many flowers make up one "Blume".

3.1.2. Basic design of a hermaphrodite ("perfect") flower

The perianth either consists of a fixed or variable number of reshaped sterile leaves, such as tepals (Leins & Erbar, 2000, p. 38) in two whorls: the calyx (with sepals) and corolla (with petals). If a distinction between sepals and petals is not possible we speak of a perigone with tepals (Leins & Erbar, 2000, p. 38). They might also be reduced, as is often the case for wind pollination, or transformed altogether in which case these elements often fulfil different functions. Then there are the female and male leaves. The female ones are called carpels and form the gynoecium and the male ones, the stamina, form the androecium. If both are present we speak of a hermaphrodite flower, and if only one is, then the flower is monoecious (male and female flowers on the same plant) or dioecious (male and female flowers on different plants)

However, as the differentiation between perianth and perigone is not always that clear, it is also suggested to drop the terminus perigone and instead refer to the inner and outer tepals (Kremer, 2013, p. 65).

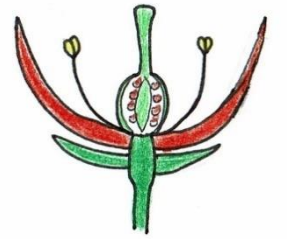

Figure 2: Hermaphrodite longitudinal section, (adapted from Heß, 2005, p.84)

For educational and teaching purposes these basic elements are used to make up an idealised model of a hermaphrodite flower to illustrate their individual functions. This simplified schema is applicable for most flowers (Kremer, 2013, p. 63). While leaves of the perianth are in indirect relation, the stamina and carpel are in directly related to the sexual reproduction (Heß, 2005, p. 83).

3.1.2.1. Sepals

The sepals are the outer elements of the perianth. They are often greenish and make up the calyx (Heß, 2005, p. 85). They are durable and their main function is to protect the inner parts of the flower. In some cases (Hamamelis ssp.) the sepals can be coloured (Kremer, 2013, p. 63). Sepals can either be free (e.g. Rosaceae) or fused together (e.g. Primulaceae) forming a tube (Heß, 2005, p. 156).

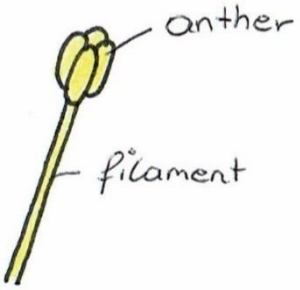

Figure 3: Stamen, (adapted from Heß, 2005, p.84)

3.1.2.2. Petals

The petals are often prominently coloured and constitute the corolla (Heß, 2005, p. 85). They are generally finer and although they too have a protective function, their main function is to attract pollinators (Leins & Erbar, 2000, p. 38). While zoophilous flowers are often brightly coloured with or without contrasts, the petals of anemophilous flowers are often reduced and plain.

Petals, like sepals, can stand free or fused and vary in their size and form.

3.1.2.3. Stamina

Stamina consist of a filament and anther and functions as the pollen-producing reproductive organ of the flower. The collective stamina form the androecium. The anther can further be divided into two thecae

and the sterile tissue between called connective. Each theca consists of two pollen sacs which contain pollen grain with the male gametes, which is released once the pollen sacs opens. They may vary in form as well, be it that they are interconnected and in adnation. (Leins & Erbar, 2000, p. 51) (Heß, 2005, p. 85).

3.1.2.4. Carpels

The carpels contain the ovule(s) and form the gynoecium. On top of the ovary is the style and the stigma, which is responsible for the reception of pollen (Heß, 2005, p. 86). There can be single or many carpels in a flower, and they can be free or fused.

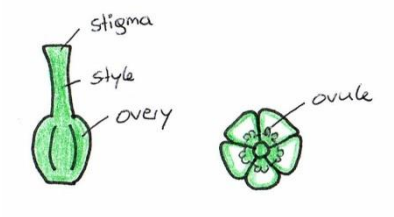

Figure 4: Carpel, (adapted from Heß, 2005, p.84)

3.1.2.5. Unisexual flowers

Normally we find hermaphrodite flowers, which contain both stamina and carpels. However, flowers that either contain stamina or carpels do exist too and are then called unisexual flowers. If a plant contains unisexual flowers with stamina on the one hand and carpels on the other hand, it is monoicous. However, if one plant carries flowers with carpels and another plant of the same species carries the flowers with stamina, this species is dioecious. (Heß, 2005, pp. 86–87).

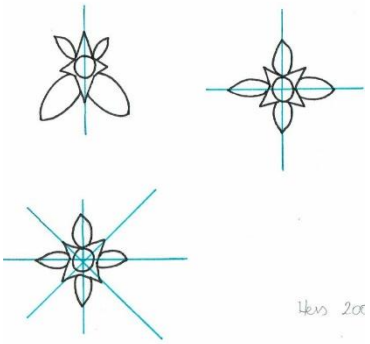

Figure 5: Floral symmetry: zygomorphic (left, above), di-symmetrical (right, above) and radial (left, below), (adapted from Heß, 2005, p.87)

3.1.2.6. Floral symmetry

Most flowers have cyclical arranged leaf organs, although acyclical ones do exists. Three different cyclical options are possible (see fig. 5). Actinomorphic flowers, often also described as “star-shaped” or “radial”, can be divided into three or more identical sectors. Dissymmetrical flowers can be divided into exactly two identical halves and zygomorphic flowers can only be divided by one plane into two mirror-image halves. (insert picture) (Heß, 2005, p. 87).

3.1.2.7. Inflorescence

A plant axis can end in a singular flower, but cluster arrangements of more flowers, so-called inflorescences, are more common. Although there many variations found in nature, only three ‘simpler’ ones (see fig. 6) will be described as they are relevant for the game concept. A raceme is indeterminate, with short flowers along the axis. The composite, also called flower head or capitulum, is an arrangement of hundreds of flowers which together form a singular flower-like structure, referred to as pseudanthium (see 3.1.1). Lastly, the umbel is a variation of raceme, with multiple pedicels

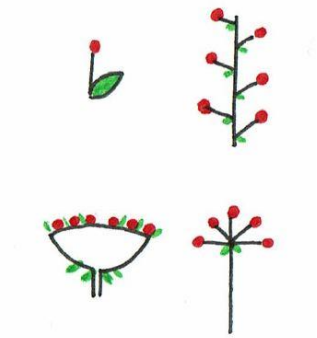

Figure 6: Some inflorescence varieties: singular (left, above), raceme (right, above), composite (left, below) and umbel (right, below), (adapted from Heß, 2005, p.88)

of equal length rising from a single point of the short axes. (Heß, 2005, pp. 87–88).

3.1.3. Flower ecology and the difference between pollination and fertilisation

This section focuses on the differentiation between pollination (German: "Bestäubung") and fertilisation (German: "Befruchtung"), as these processes and termini are often mixed up and confused in German (and in English as well), because pollination is often used to refer to both processes.

3.1.3.1. Pollination

Pollination is the process where pollen grains, produced in the anther, are transferred to the stigma (Kremer, 2013, p. 125). According to Heß (2005, p. 92), pollen can be transferred via wind (anemophily), water (hydrophily) or animals (zoophily). The first two represent abiotic pollination, while the latter is called biotic pollination (Kremer, 2013, p. 125). Zoophily can be further categorized depending on the pollinator group, such as entomophily (insects), with further sub-categories, like myophily (flies) or melittophily (bees).

Depending on whether the flower is monoicous or dioecious there are three different pollination possibilities. It is self-pollination if pollen is transferred to the stigma of the same flower. If pollen is transferred to the stigma of a different flower, of the same plant, we speak of geitonogamy and allogamy, if another plant of the same species is involved. (Heß, 2005, p. 92).

3.1.3.2. Fertilisation

Fertilisation is the process that occurs after germination and pollination. Male and female gametes are fused together, producing a zygote. Once the pollen grain has landed on the stigma by chance, it initiates the pollen tube growth and the sperm is transferred through the ovule to the bottom. Furthermore, "[i]n flowering plants, a secondary fertilisation event takes place. Two sperm are transferred from each pollen grain, one of which fertilizes the egg cell to form a diploid zygote. The nucleus of the second sperm cell fuses with two haploid nuclei contained within a second female gamete called the central cell. This second fertilisation forms a triploid cell, which subsequently swells and develops a fruiting body." [3]

3.1.4. Pollination and pollinator syndromes

In the course of evolution, plants and pollinators have co-evolved based on successful cooperation. The advantage for a flower in being attractive for the same kind of pollinator is that this pollinator may more likely visit another flower of the same type. The pollinator, on the other hand, profits from a stable and reliable source of food, in form of pollen or nectar. However, not all flowers rely on pollinators, but they may also be pollinated by wind or water.[4]

[3] https://biologydictionary.net/fertilization/#ftoc-heading-4 (16.07.2018)

[4] https://www.fs.fed.us/wildflowers/pollinators/What_is_Pollination/syndromes.shtml (31.05.2018)

Although the variety of flower types and adaptions is endless and complex, scientists have found certain patterns of abiotic pollination vectors, such as wind, water or biotic vectors, between certain pollinators and their preferred flower types. Those pollination syndromes can be illustrated in a table or figure. However, it must be mentioned that the different "syndromes" are over-simplified and only represent tendencies. Before describing the 'animal flower' syndromes, the following table provides an overview and compares the characteristics of the three major pollination agents:

Zoophily syndrome	Anemophily syndrome	Hydrophily syndrome
• Hermaphrodite flower (or pseudantium) • Angiospermy • Striking and attractive colours and odours • Available food resources: pollen and nectar (or mimicry) • Nectar guides • Pollen kit	• Inconspicuous flowers • Reduced number of organs in the perianth • Monoecious or diecious • Dense inflorescence, often hanging • Enlarged stigma • Small pollen grains and no pollen kit • No nectaries	• Inconspicuous flowers • Monocious or diecious • Filamentous pollen grains or early pollen tube growth • Enlarged stigma • Non-wettable and floatable pollen

Table 1: Pollination syndromes of zoophily, anemophily and hydrophily (adapted from Leins, 2000, p. 207)

Those features are the basis for the game mechanics and game balancing which will be described in more detail in the game document. Further patterns can be distinguished within the category of zoophily. Here flowers can be described in relation to their most frequent pollinators, such as beetle, fly, bee, wasp, butterfly, moth, bird and bat. The following table lists their most characteristics attributes:

Beetle • Relatively large, sturdy, open flower • Flower type: ‘disk’ or ‘bowl’ • Many stamina and ample pollen production • Colour of petals: white, yellowish, brownish, red • Odours: fruity and musty-fruity • Primary “beetle-flowers” lack nectaries but developed secondarily and are freely accessible	Fly • Flower type: ‘disk’, ‘bowl’ or trap flowers • Nectar freely accessible, but missing if mimicry applies as well • Colour of petals: dirty-white, dirty-yellow, green-yellow, red-brown • Odours: rotting or fruity and lemony
Bee • Flower type: ‘bell’, ‘flag’, ‘brush’, shorter ‘tube’, ‘lamia’ flowers • Nectar hidden at the bottom (15mm deep) • Colour of petals: yellow, blue, white • Nectar guides • Odours: pleasant (perfume fragrances and honeylike)	Wasp • Flower type: ‘disk’, ‘bowl’, short ‘bell’ flowers • Nectar freely accessible • Colour of petals: brown, whitish, greenish
Butterfly • Flower type: long tube flowers • Nectar hidden in small tubes (40mm deep) • Colour of petals: red, blue, yellow, rarely white • Often nectar guides • Odours: pleasant but not very strong • Often “swinging” antheres	Moth • Very long flowers, also ‘brush’ flowers • Often without landing opportunity • Nectar hidden (200mm) • Colour of petals: mostly white • Odours: intensive perfume fragrances • “swinging” anthers • Anthesis and odour emission by night

Bird	Bat
• Large and sturdy flowers or inflorescence, 'tube', 'bell', 'brush', 'flag' • Often without landing opportunity • Colour of petals: red or red-black • Odours: missing or only faint • Nectar hidden (depth varies), ample nectar production but not very sugary	• Flowers are sturdier and wide open, easily accessible, sometimes cauliflory, 'bell', 'tube', 'funnel', 'brush' • Colour of petals: dirty yellowish, whitish, greenish-violet • Odour: intensive, sourly, like cabbage • Anthesis and odour emission by night • Ample nectar, often slimy

Table 2: "Animal flower" syndromes, (adapted from Leins, 2000, p.219)

These syndromes will be used for the game to give the player guidelines for designing their flowers. They will not be simply stated but the player should deduce them from testing their hypothesis in the simulation to better grasp the importance of co-evolution of pollinators or pollination vectors and the plants.

3.1.5. Limitations

Flower ecology involves many more aspects as plants have adapted in numerous ways. However, not all aspects are similarly relevant for teaching and also not for the game concept due to didactic reduction. The game features even less subject content than schoolbooks suggest, to not overwhelm the players. Therefore, the following topics where not incorporated:

- Perigone (in contrast to perianth)
- Second fertilisation
- Development of the seed
- Seed dispersal
- Vegetative reproduction

Some of these might, however, lend themselves to be incorporated in a later expansion and "add-on" of the game.

3.2. Subject didactics

The idea of developing a game on pollination is based on from several rationals. First, while the Austrian Biology syllabus mentions flowery ecology, it does not specifically state when it should be dealt with apart from 5th grade. Approbated Austrian Biology school books introduce it, however, in 1st and 2nd grade, which is why the target group is roughly 11-12 years old. Secondly, as research has shown, a lot of misconceptions are manifested in students' perceptions about pollination, the related terminology and especially the co-evolution with the abiotic and biotic pollination. In addition, Lampert (2012, p. 87ff.) analysed schoolbooks to determine which contents are relevant, and he has highlighted their flaws. At present, Ehrendörfer (in prep.) is analysing more recent schoolbooks and is able to share first insights of her results. Thirdly, there seems to be a lack of appropriate teaching materials, especially online and animated materials. Lastly, more and more video games are implemented into classes, especially in science classes and research is catching up, studying their effects on student's motivation, engagement and learning. Still these new (video) game-based learning practises are at the very beginning in Austria, and there is only little research conducted on the topic at the University of Vienna. All factors combined gave reason to investigate the topic more closely, to try and implement the complex processes of flower ecology in a fun video game, and not necessarily a purely "serious" game, which would focus primarily on other purposes than entertainment.

As a first step, it must be established what parts of the pollination process are relevant for Biology lessons in Austria and when the topic is discussed. The syllabus of lower secondary school (10 to 14year olds= 1st to 4th grade) proposes the following contents for the 1st grade:

„An Beispielen ausgewählter einheimischer Vertreter aus dem Tier- und Pflanzenreich sind Bau und Funktion sowie Zusammenhänge zwischen Bau, Lebensweise und Umwelt zu erarbeiten, wodurch eine Basis für altersgemäßes Verständnis verwandtschaftlicher Beziehungen gelegt werden soll. Die Schwerpunkte bilden Wirbeltiere und Blütenpflanzen."[5]

This section loosely translates to: It is suggested to use native species, from both the flora and fauna, to elaborate their construction and function as well as an understanding of the relationship between construction, way of living and the environment. The focus should lie on vertebrates and flowering plants. Lampert (2012, p. 87) deduced from this that flower ecology is the perfect interdisciplinary field which combines zoology, botany and ecology and demonstrates evolution well. Furthermore, the syllabus leaves room for enough interpretation to discuss flower ecology in Biology lessons but does not specify the extent.

In order to answer the question on which content is relevant for Biology lessons Lampert (Lampert, 2012, p. 87ff.) analysed certified Austrian school books. He found them far from being without flaws, stating

[5] https://bildung.bmbwf.gv.at/schulen/unterricht/lp/ahs5_779.pdf?61ebyf (31.05.2018)

often the term “flower” (“Blüte”) is defined as “serving a reproduction purpose”. However, this is also true for “flower” (“Blume”), which leads to misunderstandings in German. Often inflorescence is not mentioned but only simply flowers. The construction of flowers is often explained by the “perfect flower” model and common examples of cherry or apple tree flowers. While stamen are explained well, the schoolbooks avoid the term “carpel” and instead refer to it as “pistil” (“Stempel”). However, discussing all issues of school books would go beyond the scope of this thesis.

At this point another - more recent - thesis should be mentioned here as well. Ehrenhöfer (in prep.) is conducting a schoolbook analysis of Austrian school books with the focus of the contents and representation of pollination parallel to this thesis. She shared some of her first insights. However, as her thesis is written in German, some examples were not translated, especially on terminology where translation proved very difficult. The analysis revealed that self-pollination is hardly ever discussed, and if, then only in the context of avoiding strategies of self-pollination. There is neither a comparison between advantages and disadvantages nor an explanation of the advantages of sexual reproduction. Furthermore, the books do not differentiate between visitors (German “Blütenbesucher”) and pollinators (German “Bestäuber”). Most books emphasise the role of insects as pollinators but do not mention others. Flower consistency is hardly ever discussed. Ehrenhöfer also found that often metaphors are used to describe the pollination processes such as “pollen travels” (“Pollenkörner reisen”) or “insects as carrier” (“Insekten als Transporteure”). There is a focus on different dispersal modes in comparison to the morphological categorization. Throughout the analysis it revealed that technical mistakes persist, such as terminological errors (“Stempel” = Fruchtblatt”, or “Fruchtausbreitung” instead of “Ausbreitung”). Regarding the building of the fruit, the books often mention that the fruit would form from the ovary. Lastly, the relevance and applicability to everyday life is rarely mentioned.

An important focus of subject didactics research at the University of Vienna are student perception surveys regarding flower ecology. Lampert (2012, p. 52ff) first conducted them and grouped the observed perceptions into seven categories, plus an extra category elaborating on the difficulties of pollination related terms. The categories are:

- Function of pollination (“Funktion der Bestäubung”)
- Sequences of pollination (“Ablauf der Bestäubung”)
- Diversity of flower visitors (“Diversität der Blütenbesucher”)
- Diversity of plants- comparison of flower types (“Diversität Pflanzen- Blütenvergleich”)
- Interaction between animals and plants (“Interaktion zwischen Tieren und Pflanzen“)
- Evaluation of zoophilism and anemphily (“Bewertung von Tier- und Windbestäubung“)
- Adaption and evolution (“Anpassung und Evolution”)

- Difficulty

The lack of appropriate teaching material is another finding of the research conducted at the Botanical Garden. As mentioned above, not even the schoolbooks are an ideal basis, often contributing to the misconceptions. A quick search on the internet revealed that there are hardly any suitable videos or animations in German[6] displaying and differentiating well between the different processes involved in flower ecology, from germination, over fertilisation and seed dispersal. The following search words where used among others: "Blütenökologie", "Bestäubung", "Befruchtung" and "Aufbau Blüte". The search proved more successful in English, however, most videos only deal with one aspect, such as pollination or fertilisation, but very rarely manage to depict the whole life cycle of flowers.
It was, however, possible to even find some games, especially video games, with a pollination theme. These games are more closely analysed in the method section of this thesis, but it can already be revealed that none really holds up to educator's or botanist's expectations of a good pollination game.

To sum up, it can be said that the recent findings as well as the lack of appropriate material, be it analogous or digital, led to the conclusion to develop a video game concept that is suitable for the use in school and adheres to the expectations of all involved. The following section elaborates on the insights concerning science learning through video games.

3.3. Game studies

Game studies is a relatively young discipline, deserving to be considered a discipline of its own given that it is scientifically studied and taught at universities, developing theories, methods and establishing specific terminology (Mäyrä, 2008, p. 4). Still, especially in the early times game studies were sometimes not regarded as an academic field, although, as Mäyrä (2008, p. 3) explained, both academic study and games share similar approaches, such as facing challenges, formulating hypothesis, creating and testing and revising strategies. Over the years, game studies established itself as an multidisciplinary field, combining approaches and insights from art, movie, literature, culture, communication and media studies, as well as sociology, psychology, philosophy and pedagogy (Beil, Hensel, & Rauscher, 2018, p. VIII).

However, this multidisciplinary and also "multidimensional" characteristic makes studying games challenging (Koster & Wright, 2013, p. XVII). Game design, gameplay and game mechanics are part of its research area, as are the theory of play, playfulness and fun, taxonomy and genre conventions, narratology and the study of their impact on players but also learners.

[6] Conducted in September 2017

A general definition is easily formulated: "*game studies is a multidisciplinary field of study and learning with games and related phenomena as its subject matter*" (Mäyrä, 2008, p. 6). However, after a more in-depth look the whole field can be overwhelming and confusing due to its multidisciplinary nature, including various, often contradicting, theories.

The historical development of game studies can be traced according to certain milestones in the past. In 1999, the game researcher Gonzalo Frasca coined the term "ludology" in reference to the "discipline that studies game and play activities (Frasca, 1999 in Mäyrä, 2008, p. 8). Other milestones, were the first online, peer-reviewed journal Game Studies, which was established in 2001 and the formation of the Digital Games Research Association (DiGRA) in 2003 (Mäyrä, 2008, p. 10). Since then, the field has vastly expanded and as mentioned in the beginning also entered further academic spheres such as universities. Books have been written about the various sub-disciplines of game studies, so this section will only shed light on those relevant for the development of the final, fun and scientifically accurate game concept on pollination.

3.3.1. Essential terms

Playing is a fundamental feature of humankind and it is argued that *Homo ludens* (playing), a term coined by Huizinga and title to his book (Huizinga, 1980), goes hand in hand with *Homo faber* (making things) and *Homo sapiens* (reasoning).
This chapter introduces some terms and characteristics of these terms that are essential to game studies, without going into too much detail of game theory, which is beyond the scope here. The terms are: game, play, serious game, gamification, game-based learning, simulation and fun.

Finding a definition for "game" or "play" proves difficult, given that both terms are utilized flexibly and ambiguously in different fields leading to oversimplification (Mäyrä, 2008, p. 33). Especially in "*the gaming industry, the meaning and nature of a "game" is hotly contested*" (Kellinger, 2017, p. 30). Before looking at different attempts to define both terms their relation to each other must be clarified. While in German there is only one word for "play" and "game", namely "Spiel", English differentiates between them. Two relationships are proposed, namely "*games are a subset of play*" as well as "*play is a component of games*" and it is concluded that both are valid and complement each other (Salen & Zimmerman, 2003, Chapter 7). Wilkinson (2016, p. 26) argues that "[t*]he distinction between play and games can be centred on the introduction of rule-systematic boundaries, taking different form, that shape playful activities". A basic definition of game might be "problem solving in a risk-reduced environment*" (Kellinger, 2017, p. 30). Juul[7] (2003) analysed seven of the most commonly referenced game definitions by Huizinga, Caillois, Suits, Smith, Crawford, Kelley and Salen & Zimmermann (who themselves compared eight definitions in order to come up with their own (Salen & Zimmerman, 2003, Chapter 7),

[7] https://www.jesperjuul.net/text/gameplayerworld/ (16.06.2018)

comparing their aspects and despite their differences, coming up with six features that make up games and a final definition: "*A game is a rule-based formal system with a variable and quantifiable outcome, where different outcomes are assigned different values, the player exerts effort in order to influence the outcome, the player feels attached to the outcome, and the consequences of the activity are optional and negotiable*." Rogers (2010, p. 3), a game designer rather than a scholar, breaks the definition down to three features: "*A game is an activity that requires at least one player, has rules [and] has victory conditions.*" Similarly, he provides a rather simplified definition of video games, which are simply "*played on a video screen*".

Most definitely the easiest way of finding a definition for "game" is by defining its characteristics which make the whole concept tangible. The characteristics of game are: It has a goal, rules, a feedback system and involves voluntary participation (McGonigal 2011 in Kellinger) but Kellinger would add fun to the list (Kellinger, 2017, p. 36).

However, "serious games" are set apart from entertainment games through their educational purpose. Their primary motive is to teach something, so they have a different purpose. They share the characteristics of games in general with a minor but essential difference. As serious games are often training or used in school or other educational facilities they are not necessarily played voluntarily. However, as pointed out by Hoblitz (2015, p. 18) the fact that students do not play voluntarily does not mean that the do not want to play at all. As the term is used rather inconsistently among different fields, a more in-depth summary of definitions is given below.

A term often brought up in relation with serious gaming is "gamification". Both concepts have in common that they may be digital or non-digital, although gamification is often supported by an application (app) (Stieglitz, 2017, p. 4). The difference is that gamification only draws on certain gaming elements to enhance processes, such as engagement, motivation or productivity often deploying gaming elements in non-game contexts, ranging from marketing, over health, sustainability, research, social media, crowdsourcing and education (Stieglitz, 2017, p. 5). Examples of these game-design principles are a levelling system, progress bar, competition, setting quests and many more. Gamification could be understood as game-based learning, although the latter is associated more with the educational sector and has defined learning objectives. Simulations and games share some characteristics, as the player may interact with them and is, to a certain degree, in charge, and both rely on computer models but also differ significantly in other respects (National Research Council (U.S.) et al., 2011, pp. 8–9). This committee concluded that simulations allow the representation, observation and interaction of processes otherwise not tangible, facilitating understanding and making predictions of behaviour.

A simulation engages the students and grants them to "*try out a hypothesis, receive feedback, revise their hypothesis, and run another simulation*" (Kellinger, 2017, p. 47)[8]

[8] 7E model in science lesson planning: elicit, engage, explore, explain, elaborate, evaluate and extend

Clark et al. (2009, p. 6) namee four dimensions for simulations for science learning: "(*a) the degree of user control, (b) the extent and nature of the surrounding guiding framework in which the simulations are embedded, (c) how information is represented, and (d) the nature of what is being modelled*". While simulations are used in a formal context games are mostly played in informal contexts "for fun". Furthermore, games have explicit rules and also goals and give feedback to the player (National Research Council (U.S.) et al., 2011, p. 9) as mentioned above.

Last but not least, a term often mentioned in relation to games and play is "fun", the very essence of play. According to Huizinga (1980, p. 3) fun as a concept is complex to comprehend and illogical. He even argues that within other modern languages there is no exact translation for it, although "*German half makes up for it by "Spass" and "Witz" together*". In neuroscientific terms "fun" can be understood as the release of endorphins, as is the case when something is learned and mastered, an underlying basic reward system. According to Koster (2013, p. 38), learning is the most important way to find fun in games, and he even refers to fun as "*the act of mastering a problem mentally*" throughout his book (2013, p. 90). Given this definition, there is no reason why "fun" and "learning" should not go hand in hand and complement each other.

3.3.2. Video game studies

Video game studies are just one sub-discipline of game studies. This section will give a brief historical overview of video games and introduce common video game genres. The focus will lie on serious games, their historical development from rise to decline and their definition in contrast to the broader term 'game-based learning'.

3.3.2.1. Historical development of video games

The first video games were already played in the 1950s, with rather simplified graphics or none. In 1971, the first arcade video game was created, and while the first could only depict graphics by using lines, a decade later, the first cartoon-like characters appeared. By the mid-1980s arcade halls were very popular and more game genres and themes developed, while graphics and controls improved at the same time. At the same time consoles (Atari 2600, Nintento Entertainment System, Playstation One) were developed and found their way into the players' home, as did handheld games (Nintento Game Boy, Playstation Portable) and in the late 1990s home systems' popularity exceeded the arcade games. With the emergence of personal computers (PCs) in the late 1970s video game programming and video game playing increased and the computer platform became the dominating platform by the mid-1990s. (Rogers, 2010, pp. 4–8).

Today, smartphones are an important platform, and statistic show that in Austria they are the most widely used device to play games on followed by PC, consoles, tablets and handhelds. We further know that out of Austrian inhabitants 4,9 m play video games, male players constituting 53% and female players 47%.

Contrary to the expectations the average age of players is 35 years, showing once again that not only children and teenagers play video games but adults as well. [9]

3.3.2.2. Video game genres

As with most aspects of game studies there is not only one approach of assigning video games to a certain genre. In fact, recently launched games often do not fit one genre but combine several, as the technological advances enable, and the players expect more complex games. The list of genres is therefore constantly extended. Still, there is a rather widespread consensus on the most common video game genres and Rogers (Rogers, 2010, p. 9ff.) groups them as follows:

- Action
    - Action-adventure, Action-arcade, Platformer, Stealth, Fighting, Beat 'em up/ hack 'n' slay
- Shooter
    - First person shooter, Shoot 'em up, Third person shooter
- Adventure
    - Graphical adventure, Role-playing game (RPG), Massively multiplayer online role-playing game (MMORPG), Survival/horror
- Construction/ management
- Life simulation
- Music/rhythm
- Party
- Puzzle
- Sports
- Strategy
    - Real time strategy (RTS), Turn-based, Tower defence
- Vehicle simulation
    - Driving, Flying

An even more detailed categorization, including more sub-genres, is presented by Wikipedia's list of video game genres[10]. Furthermore, the list also proposes the possibility to group games according to their purpose apart from the classic, conventionalized genres:

- Advergame
- Art game

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[9] https://derstandard.at/2000065784515/4-9-Millionen-Oesterreicher-und-Oesterreicherinnen-spielen-Videospiele (17.06.2018)

[10] https://en.wikipedia.org/wiki/List_of_video_game_genres (17.06.2018)

- Casual game
- Christian game
- Educational game
- Electronic sports
- Exergame
- Serious game

These categorizations do not mutely exclude themselves but rather complement each other. A serious game could be a survival game with strategical elements. This thesis focuses in the following section on educational and serious games, which are mostly implemented in school lessons, although occasionally also casual games find their way into classes.

3.3.3. Serious games

The term serious game was first mentioned by Abt (Abt, 1970 in Cheng, Chen, Chu, & Chen, 2015, p. 355) in relation to board and card games, referring to games which emphasise the educational over the entertainment factor. In general, it can be said that the history of serious games "*has not followed a consistent linear path of legitimisation, but instead moves in stops and starts*" (Wilkinson, 2016, p. 27), as it were only in the early 2000s that the term got revived. Through the Serious Game Initiative in 2002 and after a period of controversial and negative headlines concerning the impacts of video games, they achieved new popularity and attention as learning aids in the 2000s under the name "edutainment" and "serious games" (Hoblitz, 2015, p. 3). This captured the attention of the scientific community leading to a rise of studies conducted to research first the effects of video games, and later serious games, in classrooms (Hoblitz, 2015, p. 4). It can be argued that serious games have established itself as an academic field of study in 2007, the same year The Serious Games Institute at Coventry University was founded (Wilkinson, 2016, p. 36). Video games are just another form of media which lends itself to be incorporated into lessons, as were learning movies in the 1960s, PCs in the 1980s, computers with access to the internet in the 1990s and nowadays tablets and whiteboards.

Given its interdisciplinary origin, the concept of serious games exists much longer but the term was only coined later. It is argued that simulation-based learning, often in connection with military training, preceded serious games, laying out the foundations (Wilkinson, 2016, p. 28). Both are often discussed in relation to each other, but still, the conclusion is that the rise of serious games is a result of the rise of digital technologies and with it digital learning practices (Wilkinson, 2016, p. 29).
However enthusiastic researchers and educators were in the beginning, around the 2000s, the euphoria of discovering the future learning tool, serious games, died away around 2010 and thereafter because of the limitations regarding the effectiveness and quality control. The term itself became unpopular over the years, mainly because it was negatively stigmatized, given that many serious games proved to exclude the

entertainment factor altogether. Still, the scientific interest does not flag, and more studies are published than before. Hoblitz (2015, p. 7) predicts either the total neglect of serious games studies for the future or a phase of consolidation, emphasising that the latter applies to the present.

3.3.3.1. Definition of serious games

The recent consolidation of serious games studies is linked to its interdisciplinary nature which stems from "*inconsistent definitions, evaluation methods, and multiple conceptualisations*" (Wilkinson, 2016, p. 18). Hoblitz (2015, p. 13) collected terms often used synonymously by various authors, such as "digital game based learning", "learning in immersive worlds", "good digital games", "epistemic games" or "persuasive games", highlighting the inconsistency when it comes to terminology. Boyle at al. (2016, p. 186) also concluded after doing a meta-analysis that the terms "serious game" and "game-based learning" were used interchangeably throughout many studies. Cheng et al. (2015, p. 355) revealed a similar phenomenon with the term "video game" and terms such as "digital games", "computer games", "web-based games" and "online games". The variety of synonymous terms is one reason for the complexity of video games studies as well as serious games studies and it is concluded that there is no universal definition (Hoblitz, 2015, p. 16) but rather certain characteristics or categories).

3.3.4. Teaching science with video games and serious games

Although it may sound paradox at first, the notion that learning takes place while playing video games is not that far-fetched and it is not new knowledge that games can be a vehicle for learning (Annetta, Minogue, Holmes, & Cheng, 2009, p. 74). Through video games players gain knowledge and train several other skills (Kellinger, 2017, p. 6). Only in recent years the common assumption which saw "[*g]aming … as something students do outside of school … [labelling] it a waste of time*" has changed and researchers suggest the implementation of games into the curriculum (Kellinger, 2017, pp. 10–11). Back in 2011, the Committee on Science Learning: Computer Games, Simulations, and Education, deemed simulations and games worthy of further investigations but also concludes that "*evidence for the effectiveness for supporting science learning is emerging but currently inconclusive*" (National Research Council (U.S.) et al., 2011, p. 2).

The problems of traditional science teaching are manifold. Often the students are compelled to remember science facts instead of developing hypotheses and conceptual understanding, which results in disinterest for science and the connection of the subject matter to the real world (National Research Council (U.S.) et al., 2011, p. 6). Video games would allow practises necessary for learning to take place, which are, however, sanctioned harshly in schools, such as making mistakes and re-attempting (Kellinger, 2017, p. 11).

However, while some claim that commercial off-the-shelf (COTS) video games are often not fit for the implementation in the classroom, as they do not pursue specific learning objectives and "*lack academic content*" (Kellinger, 2017, p. 10), others argue that the player can learn from every game. Still, it is true

that finding COTS games which fit perfectly into the curriculum can be a tough task, as the market for science games and simulations is not yet as established as the textbook market is (National Research Council (U.S.) et al., 2011, p. 116).
Moreover, there is a problem as students, on the one hand, do not view the school curriculum as relevant to their personal lives and science teacher, on the other hand, face time pressure and standardized tests they should prepare their students for (Barab et al., 2009, p. 317).

Kellinger (2017, pp. 8–9) provides a table comparing the "*best ways to foster learning*" (achieving fluency, having a reward system and instant feedback, scaffolding,…) with the methods of how video games achieve this. These are all characteristics of games as described in the game section above, leading to the assumption that games are indeed appropriate for learning in schools. However, the school system itself presents some obstacles for implementing games in classes. Hoblitz (2015, pp. 8–9) summarized the limitations and concerns of several other researchers and educators such as limited preparation time and time in class, lack of time for thematical analysis given that the students need more time to get acquainted with the game, teachers needing more time to familiarize themselves with the hardware or get professional training, learning demotivation because the game is not challenging enough or not achieving learning goals because the students prioritize the games objectives over their learning goals. She argues that motivation to learn must be present to achieve the learning goals and that simple motivation to play is not enough. However, also subtle learning takes place and players learn as well from playing without having learning goals in mind all the time.

Another argument brought forward is that it is paramount to also teach twenty-first century skills, such as digital age literacy, inventive thinking, high productivity and effective communication techniques (Annetta, Cheng, & Holmes, 2010, p. 101). Still, it is understandable that positive results and evidence needs to be delivered for the education sector to invest in this new learning approach or tool for learning. Finding the right balance between learning, playing and motivation is no easy undertaking, considering that learning and motivation are closely connected, as is playing and motivation given that it is a voluntary action (Hoblitz, 2015, p. 9). The National Research Council (U.S.) et al. (2011, pp. 84–85) promotes an informal setting especially for science learning and lists "*freedom to pursue a wider variety of learning goals, a greater focus on increasing the learner's interest and excitement, opportunities of individualized learning and more flexible time structures*" among the advantages. Furthermore, a new approach engages the students with science and can also show the relevance of science to their daily lives and provide a space to explore and experiment.

However, especially in the last few years research has advanced significantly for educators to come to the conclusion that games " have the capacity to engage and challenge players, to present complete representations and experiences, to foster collaborative learning and to promote deep learning that

effectively connects with the dispositions and orientations of young people today" (Beavis, Dezuanni, & O'Mara, 2017, p. xii).

4. Game Design

With the video game industry on the rise a new occupation arises with it, the one of game designers. Most well-known game designers have started out with different occupations, mostly due to the fact that no specific training existed and most of them were self-taught or started as testers or level designers (Roger in Wolf & Perron, 2014, p. 85). Take Jane McGonigal, PhD, for example who studied theatre before she applied for a writer and mission designer position at Go Game (Fullerton, 2014, p. 49), or Christina Norman, who exchanged her unfulfilling programming career after convincing the lead designers for a game design career (Fullerton, 2014, p. 23). Both women are now very successful as video game designers. Although game design principles apply to board and card games as well, this section will specifically focus on video game design.

Especially when it comes to educational or serious games a discrepancy can be observed as three different parties have to come to terms. First, educators bring their expertise to the table regarding the kind of content and the amount. The setting itself, in which they work and intent to implement the games, namely schools, sets the parameters regarding the time frame and the maximal hardware requirements, as school's IT equipment is often limited and not up to date. An argument often brought forward by teachers is the lack of time, which restricts them from using games in their lessons (Hoblitz, 2015, pp. 8–9). Secondly, scientists and researchers impose yet other requirements, often related to the correct representation of the content, which, however, often proves to be too complex and detailed for a game. The third party involved are the game developers, whose job is rather challenging in this constellation, as they not only have to satisfy and entertain their players, but also adhere to the high scientific standards and tailor the games so they might easily be implemented in the classroom.

As mentioned in the beginning of this section, game design studies itself is a relatively new field, which, given its diverse nature, does not spawn only one valid theory which can be applied for all games and purposes. Furthermore, the community does not require overly academic texts, laying out and looking at the topic from an overly theoretical point of view, but rather they strive to produce practical, hands-on books and articles, sharing their knowledge gathered from years of working in the field in a popular scientific way. Certain methods, techniques and hands-on practises are widely established throughout the community, some of which will be described in this section, as they contributed to the final version of the game concept. Some principles apply to developing games in general and others specifically aim at games for teaching purposes. Although the focus will lie on the latter, the general principles are closely interwoven and valid for educational games as well.

4.1. Game design and the role of a game designer

Rouse (in Wolf & Perron, 2014, p. 83) starts off his definition by stating what game design not is. It is neither the programming nor the story writing, the visuals or audio, but they are intertwined with game design. He defines game design "as the creation of the interactive elements of a game, the rule sets, the gameplay dynamics and systems that run the input-output loop of any game experience". Nowadays, video games are hardly ever developed by one person alone, although there are exceptions such as Minecraft (2009) by Markus 'Notch' Persson[11]. In the past, often only one individual programmed and designed the whole game but the bigger the developing teams grow the more the members are trained (Rogers, 2010, p. 12). The bigger the industry grows the more specialized the professions become, which not only applies to the programmers and artists but also game designers. Within a designers' team there can be level, system and combat designers, as well as scripters, meaning quest and events programmer, and creative directors (Rogers, 2010, p. 15). Apart from the game designer, whom this chapter is dedicated to, there are programmers, artists (concept artists, 3D modelers, environmental artists, …), producers, testers, composer, sound designer, writer and when it comes to publishing a game product manager, creative manager, art directors, technical directors and many more are involved (Rogers, 2010, pp. 12–21).

The essence of being an game designer can be broken down into being "*an advocate for the player*" (Fullerton, 2014, p. 3). This simply refers to the fact that game designers must ensure that the player experience is always the main concern of the developers. This is the link between the developers and players, making them indispensable for the whole development process. While it is easy to get distracted and carried away with the game's graphics or story progression, budgeting or technical problems, these are no concern of the actual game designer. A game designer's job is to ensure "*that playtesting remains at the heart of the game design and development process*" (Fullerton, 2014, p. 303). Playtesting itself, as described in more detail in the previous chapter, involves further recruiting, observing, analysing and processing. The player's feedback enables the game designer to better understand how their game works and see whether the set goals are met. Others have stated a game designer is simply responsible that the game is "fun" (Rogers, 2010, p. 15).

If there is no formal education for game designers, how does one become a game designer and what do they bring to the table? A game designer's strengths lie in their passion for playing and testing games themselves and in their good communication skills, to sell the game to their team members but also to listen attentively to what the testers have to say (Fullerton, 2014, p. 6ff.) (Rogers, 2010, p. 15).

[11] https://www.redbull.com/my-en/one-man-band-the-amazing-games-made-by-solo-devs (17.06.2018)

Furthermore, game designers are good team players, take inspiration from everyday experiences, are creative and capable of working under pressure.

4.2. The playcentric approach to game design

Fullerton (2014, p. 11) proposes an approach which involves the player from the very beginning and throughout the whole design process. Often game designers make the mistake to only playtest the game with the target audience close to the end when the game is already nearly finished. They come up with a final game concept, often filling many pages, which is presented as a final product, which no one had laid eyes on before. However, a game can be as good and close to the game developers' ideas, but it will still fail if no one will buy and play the game. One way of avoiding this is directly including the target audience and playtesting during each phase of the development, and the playcentric approach proposes several steps and tips for the game designers to consider, following an iterative process pattern.

4.2.1. Player experience goals

The first step is to set "player experience goals", describing *"... the interesting and unique situations in which you hope players will find themselves*" (Fullerton, 2014, p. 12). The game designer should not necessarily start with hard facts, such as the number of players, the player's perspective or even game mechanics but simply decided on what they want their players to feel and experience and what they want them to tell their friends after they have played the game. This already lays out the foundation for the type of engagement of the players they are aiming for. After the player experience goals are set, it is suggested to brainstorm and decide on game mechanics which might achieve those goals. At this stage, writing down these first ideas in a one-page document, often called "treatment" or "concept document", helps to focus on and summarize them (Fullerton, 2014, p. 16). As postulated by the playcentric approach, testing early onwards is essential for a good game design. It is suggested to sit down with the target group and the written concept to check how the basic concept is perceived. This is just the first of many prototyping and playtesting sessions.

4.2.2. Prototyping and Playtesting

The next step involves prototyping and playtesting, not just once but repeatedly. Moore (2016, p. 15) states that "[*a] prototype is an abstraction of a game system and gives the designer feedback on how well the system works*". Game designers are advised to come up with an early physical prototype of their game which already includes the core game mechanics, while disregarding any visual representation aspects for the time being. This physical prototype should only be made by using pen and paper and other craft supplies, without spending too much time on the details but focusing on the essentials. During the playtesting, the focus should lie on the conformance of the player experience goals and the game

mechanics. If they align, the game designer may proceed, however, it is more likely that it is necessary to reverse and adapt the prototype several times, which leads to the iterative design process, meaning "*that you design, test and evaluate the results over and over again throughout the development of you game, each time improving upon the gameplay of features, until the player experience meets you criteria*" (Fullerton, 2014, p. 15).

4.2.3. Iterative design process

The iterative design process is a cyclical process, which assures the communication between the designer and the target audience. In short, it comes down to playtesting the game, be it by the designers themselves, their colleagues, play testers or even their family members. The more people are involved, the more feedback can be gathered and implemented. Salen and Zimmerman (2003, Chapter 2) define iterative design as "*a method in which design decisions are made based on the experience of playing a game while it it in development*". It comes down to playtesting from the very beginning to see how the game plays out.

While the previous paragraphs gave a quick overview, this paragraph provides, first of all, a list of the steps involved, followed by a more detailed description of the steps for good game design which are suggested by Fullerton (2014, p. 15ff.):

- Step 1: Brainstorming
- Step 2: Physical Prototype
- Step 3: Presentation (optional)
- Step 4: Software Prototype(s)
- Step 5: Design Documentation
- Step 6: Production
- Step 7: Quality Assurance

Step 1 is summarized in 3.6.1. and involves the player experience goals, the core mechanics, the first one-page document and the first testing with potential players. Step 2 involves a playable physical prototype and playtesting. That said, playtesting itself consists of much more than simply playing the game, as it involves "*selection, recruiting, preparation, controls and analysis*" as well (Fullerton, 2014, p. 271). Playtesting can be done on one's own, with confidents or the target audience. It depends on the stage of development which makes more sense when. During the early stages which are concerned with the foundations, playtesting on one's own is justified. During the structural phase, including confidents besides playing it alone is important and for formal details and refinement one should playtest with the target audience (Fullerton, 2014, p. 275). If this prototype proves successful, a "gameplay treatment" with

no more than a handful pages should describe how the game functions (Fullerton, 2014, p. 16). Step 3, the presentation, is most often required when applying for funding or to present the game to other team members. Only during step 4 does the digital prototyping start, and even if the end result should be a digital game, a lot of time is already invested in a game concept before the first bit of coding begins. The first digital prototype should be rough version, which may include temporary graphics to same time and money, and which focuses yet again on the core game mechanics. This software prototype is tested again until the gameplay seems to satisfy the player experience goals. If the basic prototype seems to work, documentation starts in step 5. Depending on preferences and also the team size, different methods are applied, from single documents to wikis and online collaborative tools. This documentation should include a list of achievable goals for the game. This ties in with step 6, where the goals are reformulated as "milestones" and assigned to the team members. Fullerton (2014, p. 20) emphasises the importance of several playtesting sessions even during this stage, and not only at the end. The last step involves fixing minor issues, but there should be no major changes to the game anymore, as the gameplay should already be solid. Still there is more playtesting involved during this phase before the game is finally launched.

4.3. Practical advice for game designers

Rogers (2010, pp. 24–25), whose book offers advice on a less scholarly and instead practical hands-on level, suggest various techniques to come up with an initial idea, such as "attend[ing] a lecture", "read[ing] something you normally wouldn't read" and playing good and even bad games. While generating interesting ideas, which may sound very innovative, one should realize that most games nowadays incorporate elements from previously published games, which does not mean that it is not fun or a good game in general (Koster & Wright, 2013, p. 79). This should rather take away young designer's pressure. Another aspect to consider is, that the game should be realizable within the team's resources and of course it should sell eventually. This links back to the interactive process, as this ensures the game is tailored to the target group and not just the developer's idea. In general, the whole game design process should not be set in stone but adapt along the way.

Not all games need a story, but some do and if a story is incorporated it should always have "*a beginning, middle and end*" (Rogers, 2010, p. 56). When it comes to the game's story, one aspect is the title of the game. Shorter ones prove more practical and memorable than longer ones, however this is up to personal preference (Rogers, 2010, p. 50).

There are many different approaches to game design, as well as different principles such as the one established by Allmer[12]. Familiarizing and reading up on famous and successful game designers will enable the designer to find their own way and approach as there is not one way of doing it.

[12]https://www.gamasutra.com/view/feature/132341/the_13_basic_principles_of_.php?page=2 (15.08.2016)

Being realistic is also important, especially for an educational game designer, as the market is currently flooded with new games. However, believing in one's idea, sticking with original ideas and loving one's project instead of copying too many elements of another game and being prepared to fail are advises by a successful game design consultant (Au, 2012, p. 257).

4.4. Gameplay and game mechanics

In order to analyse games and also come up with a game concept, game designers need to be familiar with game mechanics and the difference to gameplay. The latter refers to the "*formalized interaction that occurs when players follow the rules of a game and experience its system through play*" (Salen & Zimmerman, 2003, p. 2). However, the term is rather ambiguous as many definitions exist, but this thesis applies the one coined by Salen and Zimmerman. Rogers (2010, p. 42) explains that in the video game design "[*a] mechanic is something that the player interacts with to create or aid with gameplay (moving platforms, opening doors, rope swings, slippery ice)*". Kellinger (2017, p. 162) also defines "*the core game mechanics …[as] the actions and thinking the students need to do in order to complete the quests*". When it comes to board games BoardGameGeek[13] published a list of game mechanics on their website, such as "dice rolling", "card drafting", "movement", "voting", but also "simulation", "singing" or "storytelling". Knowing board game mechanics is essential also for video game designers, as many games start out with a paper prototype and a mechanic that works on paper can also be implemented into a video game.

4.5. Game Design for educational games

The general game design section proposed some universal applicable methods, but when it comes to educational games, be it non-digital or digital ones, there may be different foci or even additional aspects which need be considered. Finding the right balance of difficulty and choosing the right content when designing games for children is challenging. In general, the more one knows about the intended target audience the better. Still, often game designers tend not to make the games too difficult, but rather too simple (Rogers, 2010, p. 54). The question is whether teachers and educators qualify to be game designers. First, educators have the advantage of not only knowing the content but also their target group, their interests, needs, backgrounds and learning styles, better than most game designers do. They can tailor games to their curriculum. Although most teachers possess no programming skills, they bring these advantages to the table. Similarly to the general game design practises mentioned above, it is suggested to create a paper prototype and to decide then how much technology should be involved (Kellinger, 2017, p. 35).

[13] https://boardgamegeek.com/browse/boardgamemechanic (15.08.2018)

Step one is, as is the case with most game design processes, brainstorming and choosing a topic, which might eventually develop into an overall theme if the intended player expectations are taken into consideration (Kellinger, 2017, p. 40). After a theme is found, checking it for its suitability to be turned into a game and its technological requirements and the learning goals is essential before proceeding (Appendix: Topic Quest Worksheet). The next step is to think of a (progression or levelling) system for the game, to come up with a story, the characters and enemies or hindrances before turning to the quests. Lastly the story needs to be compatible with the game system, its core game mechanics, the scoring mechanism and rules. Some aspects need elaboration at this point:

- Formulating performance objectives / learning objectives – what does it mean to understand something and how to you measure it?
- Creating tension – decisions. Prisoner's dilemma

Some genres lend themselves more than others to be suited for achieving certain learning goals, and Kellinger (2017, p. 33) points out that "[e*]xcept for learning facts, most of the goals are matched with adventure, simulation, puzzle, and/or role-playing games*".

Another approach would be following the "*10 simple rules to create a serious game, illustrated with examples form structural biology"* by French researchers (Baaden et al., 2017) who write a lot about citizen science game projects:

- Define a (serious) goal
- Fine tune the balance between entertainment and serious tasks
- Enable the player to interact with scientific data
- Promote onboarding and engagement
- Manage information flow
- Provide an appropriate narrative
- Adapt your level design
- Use all modalities, in particular sound
- Iteratively assess what works and what doesn't

4.6. Design documents

As there simply is not only one way of designing and developing a game but many techniques and methods established amongst designers, the game industry has not one perfect model of a design document (Fullerton, 2014, p. 447). The layout of such a document also varies depending on the target audience, as there are substantial differences if the document is intended for the team members, the CEO, a possible sponsor or a publisher. The expectations of people from different fields on such a document also varies although all may be involved in the process, if we imagine members of university, school

teachers and game developers, as is the case for this thesis. In general, it can be said the GDD[14] "*provides the rules of the game*" (O'Donnell, 2014, p. 249), explaining the system behind the game and how the player's choices and actions affect this system. Although collaborative online tools and wikis make working on the document as a team easier, some still prefer stand-alone documents. Both have their advantages and disadvantages and so it is up to the team to decide on one method. In this section, two different methods of writing a game design document will be described, which are both relevant for the thesis' end result.
Fullerton (2014, p. 447ff.) suggests to include the following contents in a game design document:

- Overview and vision statement
- Audience, platform, and marketing
- Gameplay
- Characters
- Story
- World
- Media list
- Technical spec (optional)

The first part of the design document is a 500 words vision statement, which provides an overview and describes the core of the game. Furthermore, it is suggested to come up with a plausible "game logline", which is a single sentence to describe the game. Depending on the type of game and its complexity, the "game synopsis" may unfold on several pages, describing the uniqueness, setting, core game mechanics and painting an overall picture of the players' gameplay experience, of what they are expected to feel and see.

The next section states the demographic description of the target audience, including age, gender and often geographical locations as well. Moreover, the document articulates which platform(s) the game will run on (Android, iOS, …) and why they were chosen. Similarly, the system requirements are important to state, as this might limit the accessibility of the game. This section also gives the opportunity to name similar top-sellers in the market, as well as compare the game to its competition. Marketing and the sales expectations are also part of this section. Lastly, legal and financial obligations must be considered, be it copyright, trademarks, or licensing agreements.

The then following part describes the gameplay in more detail. It gives an overview of the core gameplay and uses the prototype as a model to demonstrate the functions. What follows is a detailed description of

[14] GDD= game design document

the different functions of the game. Controls tie in with gameplay, so illustrating the control panel is crucial. The game design document should contain all drafts of the necessary interfaces with a description of the function of them as well as flowchart with all the screens which will have to be created. Furthermore, the rules and game objects and their relation to each other need to be laid out. The winning and scoring conditions are essential for the game as well. The different modes of the game and features need to be listed, establishing whether it is a single player or multiplayer game and whether there are different modes of playing (i.e. an educational and a strategy mode as in Reach for the Sun (2013)). If the game contains a level system, all levels should be described in great detail in this section.
The next section states the game characters. This includes a detailed character design with all their attributes and appearances. It will have to include a list of the PCs and NPCs, their behaviour and the AI settings. The section with the story should first include a short synopsis and should not take up more than one or two paragraphs. This is followed by the complete story, written in a style that mirrors the gameplay. If background story elements are important, which do not directly appear in the game, they must be described here as well. The narrative devices are defined, as one should know who is telling the story or how the story unfolds. Lastly, if there appear any subplots they are described and their relation to the overall gameplay explained.

The last section which is relevant for the game designer is the media lists, which functions as a form of appendix, listing all the assets, environments, characters, animations and any music or sound effects.
The technical spec is often not part of the design document and written by the technical lead.

Rogers (2010, p. 59ff.) suggests in-between steps as preparation for the final GDD: the one-sheet, the ten-pager, and the beat chart. The one-sheet gives an overview and should not, as the name suggests, exceed a single page and include the following information: game title, intended game systems, target age of players, Intended Entertainment Software Rating Board (ESRB) rating, a summary of the game's story focusing on gameplay, distinct modes of gameplay, unique selling points (at least 5 bullet points) and competitive products. However, as the ESRB is an American rating system, it would be exchanged for the Pan-European Games Information (PEGI), or even national specific rating systems.
The ten pager goes into more detail while not overdoing it at the same time (Rogers, 2010, p. 63ff.) (Rogers, 2010, p. 435). There might be two different audiences which this document is targeted at, namely the team and the marketing department or potential sponsors. Therefore, it is essential to present this document well, using catchy and persuasive language and visuals. It can be created using PowerPoint, making it handy to present. This is the suggested structure for the ten-pager:

- Title page
- Game story and game flow
- Characters

- Gameplay
- Game world
- Game experience
- Game mechanics
- Enemies
- Cutscenes
- Bonus material

The first page is the title page, including the game's title, intended game systems, target age of players, the ESRB rating and the projected ship date. The second page gives a summary of the game story and game flow, including information about the encounters and challenges, the level progression and connections to the intended general gameplay experience. The third page is about the characters, their appearance, abilities or special equipment, mapping out the basic character controls. The fourth page is reserved for the gameplay, describing the sequence of play and the level system if there is one. The fifth page presents the game world in which the player navigates. The sixth page lays out the game experience, the "*overall gestalt of your game*" (Rogers, 2010, p. 68), how the game feels, what the player sees, which "*emotions/moods are meant to be invoked*" and a flowchart showing how the player would use the interface. Page number 7 presents the gameplay mechanics, hazards, power-ups or collectibles or the economic system of the game if applicable. The eighth page presents the enemies; the ninth cutscenes and the last page any bonus material.

The last tool is the beat chart, which is in close connection with the gameplay progression. It lists the level, story element, progression, estimated play time, mechanics, hazards, rewards and background music and provides a colour scheme.
Another document which might be needed is the pitch, often in form of an PowerPoint, which is often needed to find and convince publishers (Rogers, 2010, p. 417). Moore (2016, p. 12) explains that "[*t]he pitch paper is meant to illustrate the essence of the game and explain why it would be new and fun to play*". Last but not least, the designer should be equipped with all necessary information to write the GDD, which goes into too many details to elaborate on it further at this point, but a good template is provided by Rogers (2010, p. 446).

Another term which appears in close connection with game design it the 'high concept', stating the basic concept of the game and should be formulated in a sentence with the maximum of 20 words (Moore, 2016, p. 12). As mentioned in the beginning of this chapter, depending on the game design document's purpose and target audience, its length may vary as will the weighting and emphasis on certain aspects. However, even if on average design documents exceed 300 pages, the community seeks to keep them as short as possible (Rogers, 2010, p. 59). It must be noted that each developer or company favours and

focuses on different aspects for the GDD. Moore (2016, pp. 14–15) arranges his GDDs in four parts: introduction, game mechanics, game graphics and appendices. These are just a few texts describing the process of coming up with a game design document in a somewhat scientific and structured way. The templates may not fit every genre, as some, such as simulation, arcade or puzzle games need no story or central character (Moore, 2016, p. 12).

5. Method

This section describes how I approached the development of a video game about pollination. Besides doing research on the subject matter, which is summarized above in the theory part, and finding concrete evidence for the use of games in classrooms, which is described in the section below, the game design process required a lot of researching games and playing them. First, best practises of video games were played and analysed. The all have in common that they are COTS games and not specifically designed serious games. Still, they are used successfully in an educational setting. After that the search for good biology related games (boardgame and digital) began which again were rather COTS games and did not directly pursue an educational goal. Then, the scope was narrowed even further and a close analysis of existing video games on pollination followed with special focus on the game's objectives, the gameplay and a general evaluation which includes the concerns from the perspective of game designer, specialist and player, the three parties a good game should satisfy. These steps then lead to the final game concept and result of this thesis described in the following chapter.

5.1. Evidence for using games, serious games and simulation in (science) education

Meta-analyses have gathered the results from the last decades, depicting which effects of using video games as a teaching tool can be proven. The National Research Council (U.S.) et al. (2011, pp. 54–55) came to the conclusion that there is more evidence supporting the effectiveness of simulations for science learning, while evidence on games is inconclusive and that there are many gaps and weaknesses in the body of research. They concluded that "[s*]imulations can advance conceptual understanding*" while there is only moderate evidence on supporting "*student's interest in science and science learning*" and even less evidence "*supporting [the] development of science process skills and other learning goals*".

A more recent study concluded that one of the weaknesses in the body of research is *"…that there is a large diversity in the way that experimental research on DGBL [digital game based learning] effectiveness assessment is conducted, making comparison of results across studies difficult*" (All, Nuñez Castellar, & Van Looy, 2016, p. 91). Another problem is that follow-up studies are often not conducted, making it difficult to distinguish between short-term benefits and overall sustainable effectiveness (All et al., 2016, p. 101). Furthermore, they point out that the instructor is sometimes too prominent, that often other confounding elements are introduced, making it difficult to distinguish of whether the effect would have taken place without these elements, and that more information should be provided about the experimental and control conditions. Overall it can be said, that games should be studies in isolation as much as possible (All et al., 2016, p. 101).

As mentioned above, the lack of research and the weaknesses of existing studies make it difficult to draw conclusions. Most studies address the use of video games in science classes and given that the number is rather small, it comes as no surprise that "[*e]ven fewer have been concerned with the effect of video games in biology education…*" (Barko & Sadler, 2013, p. 30).

The study by Barko and Sadler (2013, p. 29 ff.) used an educational video game to teach biotechnological materials and tools in three classes. While all three "*demonstrated gains on a curriculum-aligned test*", two classes "*showed gains on a standards-aligned test of content*", suggesting that "*video games can be useful in classroom contexts*". It also was found out that the student's attitude towards science was not significantly affected.

Although single studies are interesting, it soon became apparent that too many studies were conducted about the use of video games for teaching and learning, which is why meta-analysis were likely to provide more insights.

Boyle et al. (2016, p. 187) found 512 studies about positive effects of digital games in a five year period (2009-2014) while Connolly et al. (2012, p. 126) had identified 129. This shows the rapid increase in research conducted and the interest in the topic. Out of 129 studies analysed by Connolly et al. (2012, p. 661), 21 were about health, 14 about social issues, 11 about science, followed by mathematics and statistics, engineering and computing, language and history (Connolly et al., 2012, p. 666). Grouped according to their outcomes 33 were affective and motivational, 32 reported knowledge acquisition/ content understanding, 20 perceptual and cognitive skills, 13 behavioural change, and fewer physiological outcomes and social/soft skills outcomes. The evidence is considered empirical, except for social skills. Overall, there was no strong evidence suggesting learning with games is more effective (Connolly et al., 2012, p. 671). However, it was also concluded that the chosen categories for outcomes are too broad and that some may need sub-categories. Unfortunately some parallels to the previous study were found, as most games still focus on knowledge acquisition instead of conceptual understanding (Boyle et al., 2016, p. 187). Furthermore, the analysis shows that less COTS games are used, given that they are often difficult to integrate (2016, p. 188), but it is also mentioned how costly and difficult the endeavour of making an educational game can be.

Although the evidence becomes clearer with every study and meta-analysis, there are still difficulties and limitations as with every learning principle and learning tool. The evidence suggests that is it is indeed worth to invest in the development of educational games and teacher training, because if teachers do not feel confident games will never find their way into classrooms on a wide scale.

5.2. Game based learning best practises

As was concluded above, serious games have been studied and continue to be studied intensively but research shows consolidation, due to the non-significant results. However, not only serious games, games which were specifically developed for teaching, can be implemented in the classroom, but many off-the-shelf entertainment games as well. Indeed, it was found that games which were not specifically designed to support certain skill acquisition managed to achieve that nevertheless (Connolly et al., 2012, p. 671). This War of Mine (2014) developed by the polish 11bit studios is an excellent example of a survival game which was not developed as a serious game but contains some very serious topic. It shows the real and ugly face of war and portraits well that often tough decisions have to be made in order to survive which might have fatal consequences[15]. Recently, a new version has been released, where the player plays from a child's perspective in This War of Mine: The Little Ones (2016). Another example is Minecraft (2011), which is a sandbox survival video game, where the player modifies the environment by mining its different resources (wood, stone, soil, …) and crafts new tools and materials. There is no real game objective but only what the player wants to do. It is commonly used by teachers in school. Many games lend themselves to be used in history lessons, such as Crusader Kings II (2012), Europa Universalis IV (2013), Civilization VI (2016), but also the Assassin's Creed series (2007-). The latest release from that series, Assassin's Creed: Origins (2017), even features a "discovery tour" which excludes all combat scenes and quests and lets the player simply wander ancient Egypt[16]. Other games offer the possibility to train construction and management skills and teach students budgeting such as Planet Coaster (2017), where players plan an amusement park.

This list could go on, but its primary purpose is to show the diversity of commercial off-the-shelf games. These games all have in common that they are good games which challenge their players and engage them and offer them possibilities to train skills such as creativity, empathy, management, budgeting and many more.

5.3. Biology games

Of course, there are various games with specific biological content as well. This section will shed light on both commercial off-the-shelf games but also "serious games", be it analogue or digital, which thematise biological aspects. First, an overview will be given, but the focus lies specifically on games which draw on plant biology, pollination or gave inspiration for the final game design.

[15] http://www.thiswarofmine.com/#home (09.07.2018)

[16] https://support.ubi.com/en-GB/Faqs/000031846/Discovery-Tour-Mode-of-Assassin-s-Creed-Origins-ACO (09.07.2018)

5.3.1. Tabletop games

Tabletop games are, as the name suggest, played on a table and include board games, card games, dice games, but also miniature wargames or tile-based games. A good source to browse through existing board and card games is boardgamegeek.com[17] which offers reviews and an overall rating, basic information such as number of players, average play time, age suggestion, but also pictures and a detailed description.

An example which was also the model for the pollination biology game is Evolution (2014) by North Star Games. The game is based on the game Evolution: The Origin of Species (2010), which was created by a Russian biologist but modified by the developers of North Star Games. It is a resource management game, where players create species by adding cards with special traits (hard shell, fat tissue, cooperation, defensive herding, etc.) and thus adapting them to survive and to get more food tokens than their competitors and to not fall prey to carnivores. Since 2014, many expansions have been released, which introduce flight evolution or different climates as well as new trait cards. The game can be played in class, although many copies would be required for larger classes. However, the developers have created a digital beta version called Evolution - The Video Game (2017-18), launched another successful Kickstarter campaign and want to release soon[18]. The digital version promises single and multiple online player mode and shorter gameplay sessions, which might be even more appropriate for school. Another good feature of boardgamegeek.com are the forums where players discuss using the game to teach evolution[19] but also other evolution themes games and even scientific reviews of them. West (2015, p. 192) tested evolution games with teenagers and graduate students and praised Evolution (2014) for its simple but tactical gameplay. Furthermore, he concludes that the card game "features sophisticated biology", depicting evolution well, as "the best strategy depends on what everyone else is doing" and suggesting it as a teaching tool for ages ten and up, as it "captures key aspects of the evolutionary process".

The two other games West tested were Terra Evolution: Tree of Life (2015) and Evolution: Random Mutations (2013), both no real competitors to Evolution (2014). An interesting plant focused expansion for Evolution: Random Mutations (2013) is Evolution: Plantarum (2016), which lets the player discover the complex symbiotic link between plants and animals. Recently, a young Swiss team of game developers started a kickstarter campaign for their new game Darwin's Choice (2018). The game will, however, only be published in the course of the next year, so there are no game reviews yet but only

[17] https://boardgamegeek.com/ (09.07.2018)

[18] https://www.kickstarter.com/projects/northstargames/evolution-the-video-game/description (09.07.2018)

[19] https://boardgamegeek.com/thread/1580710/using-game-evolution-teach-evolution (09.07.2018)

sneak peeks of the elements and style. It is similar to Evolution as players come up with their own species by combining animal traits[20].

Another game with biological content is Bios: Megafauna (2011). Origins: How We Became Human (2007) follows the past of our ancestors from Africa to all continents, displaying the changes in anatomy and also brain size that eventually led to *Homo sapiens*. Go Extinct! (2014) familiarizes the player with a simplified evolutionary tree with the aim of finding sets of closely-related animals.

A game that was recommended to me by Peter Lampert, my co-supervisor, is Terraforming Mars (2016) after I had mentioned terraforming as a feature for the pollination game design; it is currently ranked the 5th popular game on boardgamegeek.com[21].

A search on boardgamegeek.com even revealed a board game on pollination: The Pollination Game (1977). Unfortunately, it was not possible to get hold of a copy of the game and the publisher admitted that the game has not been reprinted in the last decades. However, it was possible to acquire photos and the rulebook. The game consists of 72 cards, which either feature types of flowers (bee flower, fly flower, …), pollinators (bees, bumblebees, flies, …), or conditions (disasters, frost, rain, night). The goal is in most cases to find a pollination match, two flowers of the same kind and one pollinator. The deck enables the players to play various games with minor differences concerning the goals. The cards are very artistic and accurate and some also include little descriptions. Apart from the games mentioned here, there exist for sure many other educational games and quartet card games which have something to do with ecosystems, plants or biology in general. From personal experience it can be said that many more games focus on genetics and immune systems or on animals than on plant biology, which holds also true for video games with a biological focus.

5.3.2. Video games

Finding video games with biological themes is more difficult, as there is not simply one homepage listing and reviewing all of them. As a first step, several digital distribution platforms such Steam, GOG Galaxy and itch were browsed using search words or filters. This first step was supposed to reveal not only biologically themed games in general, but already those focusing on plants and pollination. Steam only enables one to search for games by genre and key words, such as “biology” or “plant”, but steam mostly features purely entertainment games. However, analysing games, even if they are not purely “serious”, helps to brainstorm for ideas and game mechanics. Plants vs. Zombies (2009) is a very successful tower defence video game, which was followed by many sequels. Each level the player may prepare for the zombie waves by planting different plants trying to protect their houses. As the zombies become more

[20] https://boardgamegeek.com/boardgame/250309/darwins-choice (09.07.2018)

[21] https://boardgamegeek.com/boardgame/167791/terraforming-mars (31.05.2018)

specialized throughout the game so do the plants, and so the player is introduced step by step to their special attributes and may combine and try out different approaches with each level. Although the plants are invented and not present in nature, the basic game mechanic was very appealing and therefore considered in the initial brainstorming and design process. Spore (2008) also offered inspiration in the brainstorming phase. Here the player may simulate the development of a species from the beginning, the cell stage, over the creature and tribal stage, to civilisation and space stage. Spore is famous for its creature creator, where the player may individualize its species by applying the traits that were unlocked during the game. Another game which was found via gamesforchange[22] and steam is Reach for the Sun (2013), which is a learning game by FilamentGames about photosynthesis. The player starts with a sunflower and may unlock further flowers. The goal is to manage its resources well for a whole life circle (spring to winter) and produce flowers and seeds, which are the game's currency. The game features a classical mode, where the produced resources, water, starch and nutrients, have to be collected by clicking on them, adding time pressure. The strategy mode is turn-based and here the resources are automatically collected and the player may spend them on parts of the plant such as leaves and stems to grow it. The game features an encyclopaedia, called "almanac" which not only provides tips for playing the game but also further biological knowledge. Some words provide a definition which is also read out to the player. The studio has also released games on programming, fossil forensics, planetary conditions, language learning, maths and many more.

A similar game is Plant Growth (2013), where the player collects resources (sugar, minerals) to grow their plant. Compared to Reach for the Sun it is less railroaded, giving the player more options to also fail and see the consequences of bad investment in too many or less leaves and roots. However, Plant Growth is a free Android game, which shows as the graphics are not nearly as nice and the game lacks fun game mechanics.

Many other games have been played and quickly analysed, also with different topics to gather as many ideas as possible. However, the focus of the analysis clearly lies on the games about pollination. Before developing a new game, an essential step is analysing and expecting the state of the art to come up with something new and unique. The problem here, however, is that there is not pre-defined way of doing game analysis. Every university and institute follows a different method and checklist, which vary in detail and length. Therefore, the following chapter will briefly introduce how the games where analysed before analysing the games on pollination.

[22] http://www.gamesforchange.org/games/ (07.03.2017)

5.3.3. Analysis of existing video games on pollination

Game analysis techniques are quite diverse and first and foremost depend on their purpose. In this case, the goal is to find any game which deals with pollination, and to analyse it from two different perspectives: the game developers' and the biologists'. This is different insofar as most game developers are only interested in the game mechanics and gameplay, as subject matter is treated often as a theme, which is not the case when it comes to serious games, where the focus is on the content and not entertainment.

In order to make the games a bit more transparent and comparable, each analysis starts with the contextualization and "hard facts": The game's name, the year it was first released, the most recent version number, the game developer(s) and publisher(s) and publisher's location, as well as the available languages and the platforms the game was released for. After that the game objective is briefly explained, meaning what the player has to achieve in order to win. This is completed by a description of the gameplay, which is necessary for the evaluation. The evaluation follows certain parameters, although not all can be addressed to keep the analysis as precise and relevant as possible. The focus lies on the especially good, as well as the problematic ones, which also influenced the design of the final game concept of this thesis.

Gameplay-wise, the parameters examined are the ones mentioned in the game design section above: aesthetics and visuals, controls, progression, balancing, as so forth. Although the analysis of these parameters might be subjective, it is always with the consideration of the game design principles that were elaborated before. Subject matter-wise, the games are evaluated concerning the representation and accuracy of their biological content. While it is clear that some content reduction is necessary, the main criticism concerns false representation which might foster false assumptions about the content by the players. This analysis in general is a delicate one, as usually experts on the field, game designers and players have different views on how a game should look like. Taking all these parameters into consideration is therefore a challenging task.

After scanning various platforms and games provider, such as Steam or Google Play Store, a variety of video games on pollination have been identified. The following section briefly describes the state-of-the-art while also evaluating the games according to their correct representation of pollination. Furthermore, the games are looked at from a game designer's perspective, as often 'incorrect' features serve the playability of a game. As far as possible, the game developers were asked about their game's specific information and their intention, but it showed that most did not reply even after being contacted repeatedly.

Another game which will be released in autumn 2018 has to be mentioned here as well: Bee Simulator (2018)[23]. This game is not part of the in-depth analysis as it has not yet been released. However, according to the description and the video trailer it can be said that this COTS video game will let the player explore Central Park from a bee's perspective and that pollinating flowers is also part of the game. In how far the representation adheres to specialist's expectations and whether it lends itself to be implemented in biology classes cannot be answered at this time.

[23] https://store.steampowered.com/app/914750/Bee_Simulator/ (11.08.2018)

5.3.3.1. Polinizapp

Name:	Polinizapp
Year:	2012?
Version:	/
Game developer:	Real Jardín Botánico de Madrid (RJB) + Instituto Mediterranea de Estudios Avanzados (IMEDEA) + Fundación Espanola para la Ciencia y la Tecnología (FECYT)
Publisher:	Real Jardín Botánico de Madrid (RJB)
Publisher's location:	Madrid, Spain
Language(s):	Spanish, Catalan, English
Platform:	mobile (Android and iOS)

Game objective:

In Polinizapp, the player controls a pollinator and must visit target flowers for two reasons, namely to collect pollen and nectar and thereby extending the time left to play, and to earn as many points/seeds as possible. A point is earned if the pollinator visits two target flowers of the same type, pollinating them and producing a seed.

Gameplay:

At first the player is informed about pollen and nectar, with a short definition of both:

"Nectar is a liquid made by flowers as a sugary treat for the pollinators" and "Pollen is the male gamete of flowering plants. It is made in the stamens of flowers and" – here the English description just stops. Then the player may choose a pollinator to play with, however, in the very beginning, there is only one available pollinator, the honey bee (*Apis mellifera*), as others (bumblebee, carpenter bee, pollinator fly, …) have to be unlocked with seeds. Once a pollinator is chosen, the player gets further information about this pollinator. In the case of the honey bee: "*It feeds on pollen and nectar. It saves the nectar in the crop and the pollen is stored in [a] "small baskets" that it has on its hind legs. Generally, it is only able to pollinate flowers effectively when they have very open corollas where pollen and nectar are accessible*."

The next screen informs the player about the target flowers of the pollinator, which are starflower (*Borago officinalis*), rockrose (*Halimium halmifolium*), broadleaved [lavender] (*Lavandula latifolia*),

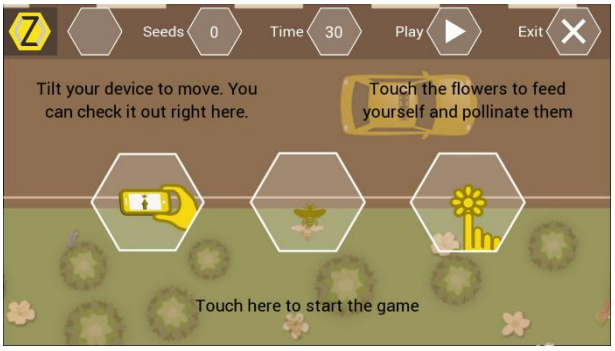

Figure 7: Level interface (taken from Polinizapp)

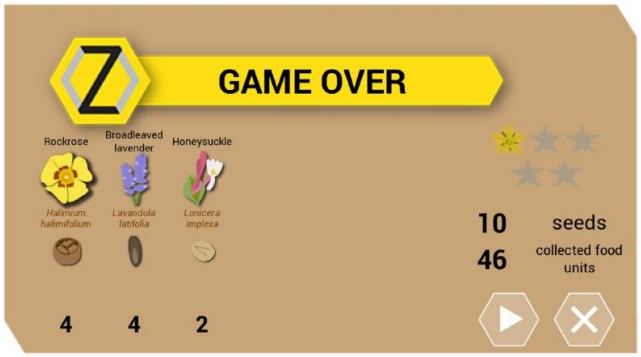

Figure 8: Feedback after game over (taken from Polinizapp)

honeysuckle (*Lonicera implexa*) and almond (*Prunus dulcis*) for the honeybee.

What follows are the possible threats for this pollinator, which the player must avoid during the game. For the honeybee the threats are: Asian hornet (*Vespa velutina*), vermin, pesticides and natural predators. Lastly, there are different environments for the player to choose from: mountains, city, Mediterranean field and crops. With the last instructions, namely tilting the device to move and touching flowers to feed off and pollinate them, the game begins. Initially the player has 30 seconds for this round, which gets extended the more flowers are visited. The game is over once the counter reaches 0. The game over screen features information on the number of the collected food units and seeds, while also differentiating how many seeds of which target flowers have been collected. Moreover, it shows five flower symbols, which are grey unless a special condition has been fulfilled during the game. However, nothing indicates what this special condition is or what the use of these symbols can possibly be.

As indicated before, once enough seeds have been collected a new pollinator is unlocked, namely the bumblebee.

Evaluation:

Visually the game is very appealing with a consistent design and clear interface and, instead of overwhelming the player with a lot of text, it is their decision to click on the flowers or threats for more information. However, certain texts, such as the pollinator information text, are always shown, even after playing the game for quite some time. This is a bit redundant even if one can skip these texts by clicking the arrow button to proceed to the next screen. It is good that they have included definitions and the Latin names for the pollinators and flowers, but the English version of the game is full of grammatical and spelling mistakes, giving it an unprofessional touch.

Moreover, moving the pollinator in this tilting-controlled mobile game is rather tricky, especially as one must tap on the flowers at the same time to refill the pollen and nectar supplies and pollinate them. The problem with a tilt-controlled game is that the whole game stands or falls with the controls, meaning that in this case the trickiness is not interpreted as a challenging factor but rather frustrating, and does not urge the player to proceed and try again. Another irritating factor, as mentioned above, is the fact that nothing indicates how the bonus-flowers are earned or what they can be used for. Even after playing for quite some time, a pattern could not have been identified.

From a biologist's and botanist's point of view, the major criticism is that the player controls the pollinator and is very much focused on the production of as many seeds as possible. However, simply because a pollinator visited two flowers of the same species it does not mean that the flower was successfully pollinated. Furthermore, the game does not differentiate between pollination and fertilisation,

two processes often mixed up by students. Another false image is created as the game ends with the death of the pollinator. Players could believe that the sole purpose of the pollinator is to feed, pollinate and die, while especially in the case of the honeybee the insect would want to return to the hive. Also, pollination is rather a passive action and not directional as the game would make one believe. By visiting two flowers of the same type the player pollinates these flowers and generates one seed, which might make the player believe that the pollinators collect the seed which is not true.

From a game designer's perspective, it makes sense to implement a time factor which challenges the player, as well as enemies, and to have a simple goal, namely to acquire as many seeds as possible. The seeds act as incentive as they are the game's currency, which the player may spend to unlock and play with different pollinators. The game gives the player feedback at the end of an attempt, listing the pollinated flowers, and indicating the number of seeds and food units that were collected. There seems to be the possibility to acquire special points, as there are always five grey star flowers on the right-hand side, but how is not revealed in the game. On the one hand, the game is not overloaded with text, but on the other hand, some features are not completely clear and would require further explanation.
Overall it can be said that the game has a clear and appealing layout and manages well to balance game design and biological elements, although it could be updated and improved.

5.3.3.2. Pollination2Plate

Name: Pollination2Plate
Year: 2013
Game developer: Nicholas Colgrove and Vishal Singh, Educational Media, University of Nebraska- Lincoln
Publisher: University of Nebraska- Lincoln
Publisher's location: Nebraska, U.S.A.
Language(s): English
Platform: mobile (Android)

Game objective:

Pollination2Plate teaches the player about the benefits of pollination. The player matches various foods with one of the three different modes of pollination, direct, indirect or wind, within a certain timeframe to score as many points as possible. The game is over if ten items were correctly assigned to the categories.

Gameplay:

The menu interface allows the player to either press "play" or "about". The latter gives detailed information about the people involved in the concept and development process and contact information.
Once the player clicked on "play" a rather long information text about pollination follows:
"*Pollination is an essential ecosystem service. It is necessary for plants to produce viable seeds. From these seeds, new plants (offspring) grow. Pollination is essential in plant reproduction and it allows plants [to] share their genetic material. Pollination is necessary for fruit and vegetable production. The fruits and vegetables we eat are often produced by the plant to protect and nourish the seeds. Without pollination these protective structures, that we harvest and eat, would not form.*"

They inserted a cross-section of a "perfect flower" with the description of the various parts of a flower and their function. However, the picture is not centered and therefore part of it not visible on the left. The text continues with the detailed description of pollination, the reproductive parts, pollinator attraction, self- and cross-pollination and the transfer of the pollen in even more detail. They stress that pollination is not an intentional process but rather accidental. The last section explains the "direct" and "indirect" connection of everyday food to pollination. "Direct" is thereby defined as a food product which is the direct result of pollination, such as fruits. "Indirect", on the other hand, refers to a food product which is the results "*from eating a pollinated crop*" . The given example is milk, which can be produced by cows if they eat alfalfa, a crop. The last method of pollination is wind, where no pollinator is involved.
Reading all this is optional and the player may just skip right to the actual game.

During the game the player simply has to drag and drop the food items which appear in the middle of the screen to one of the three pollination buttons (wind, direct and indirect). If a food product is wrongly assigned there is a 5-point penalty, while the score increases by +10 if the correct category was chosen. A small bubble in the upper right corner indicates the current score, the counter until 10, and the "time to complete". Once a product was dragged and dropped correctly the timer stops and the player gets further information about the items. Examples:

Figure 9: Interface after an item was assigned to the right category (taken from Pollination2Plate)

- Steak → indirect pollination: "While bees do not pollinate cows, they pollinate many of the forbs they eat."
- Macaroni → wind pollination: "Pasta is made from wheat that is wind pollinated."
- Chocolate → direct pollination: "Few realize the world's supply of chocolate depends on midges, tiny no-see-um flies, the cacao flower's pollinators.
- Cantaloupe → direct pollination: "Squash bees and honey bees are critical pollinators of this tasty summer fruit."
- Atemoya → direct pollination: "[T]his rainforest fruit results from Nitidulid beetle pollination. In most cased commercial growers must hand pollinate as these beetles are not present outside of the plants native range.
- Morel Mushrooms → indirect pollination: "[T]hese delicious mushrooms, are sometimes found around apple tree roots. Without pollinators, apples would produce less seed. Less seed = less apple trees = fewer morels.

If 10 items were sorted correctly the round is over and the player sees their score and the time needed for completion. After the first round, where only two items need to be sorted, the player progresses to the actual game mode and 'intermediate' status where ten items need to be categorized. The second round is 'advanced' mode and from then onwards items from all levels are mixed together.

Evaluation:

The game tries to make pollination attractive and emphasizes its importance through the connection to everyday products, which is also one plead from Lampert (2012, p. 124). Most food items are relevant for students, and the short information which appears after an item was assigned correctly, is insightful. However, the introduction about pollination is rather long, and although precise and interesting for someone studying Biology, it might be too long for students. Moreover, the player has to close the game and start anew or click on 'new player' in the upper right corner, to see this info text again. However, the previous scores are then lost. Regarding the long information text, the developers enabled the player to

zoom in to read it better, but as mentioned above, the cross-section of the flower is not centered and therefore some terms not legible at all.

What is rather confusing is the fact that the categories on the bottom appear in a different order once a new round starts, which often results in minus points because the player is so used to the previous order. Similarly, it is frustrating if a shown food item is wrongly assigned only because the product is processed food, containing several ingrediencies and the player does not know which is the relevant one. An example would be cherry pie, which the developers assigned to direct pollination because "[t]he filling contains cherries pollinated by bees and flies"; however, the player mind think that pie is about flour (wind pollination) or milk and eggs (indirect pollination), making it an ambiguous example. Another misleading example is morel mushroom, categorized as indirectly pollinated as "these delicious mushrooms, are sometimes found around apple tree roots. Without pollinators, apples would produce less seed. Less seed = less apple trees = fewer morels." The player might however think that mushrooms are indirectly pollinated, confusing the reproductive cycle of fungi and other plants.

A botanist may welcome the in-depth explanation of pollination in the beginning, although a lot of information is thrown in there with little to no well phrased transitions, making it hard to understand for players with no biological background. However, some sentences are also misleading, simply incorrect or should be better elaborated.

First, "*pollen [is not] a sticky substance*", but pollen grains may be coated with pollen kit, especially among zoophilic flowers, where pollen is packed thereby together in bigger packages, while the surface of wind pollinated pollen is often dry.

Secondly, the difference between self- and cross-pollination is briefly stated but why both methods co-exist and are relevant is not explained. It is also mentioned that "*flowers are male or female*" while "*other flowers have both male and female structures*" but the reason for or benefit of both is omitted. In addition, simply labelling plants as either 'female' or 'male' is too simplified and could cause misconceptions of the pollinating process.

Thirdly, the categorization into 'direct' and 'indirect' pollination is a rather infelicitous drafting, considering that direct pollination is often synonymously used with self-pollination, while the developers refer to direct pollination if the product itself is eatable in contrast to food items resulting from eating pollinated crop.

Still, the quint-essence, the fact that "pollination is accidental" as animals do not pollinate intentionally is emphasised. Furthermore, the syndromes for anemophily and zoophilism are mentioned.

The game design is very simple and not very engaging. The overall score is not saved in a list, so the player cannot compare their performances. Especially in the beginning, it is confusing, while after some time the little notifications after an item has been assign to the correct category are redundant and

annoying. There seems to be a levelling system but it is not explained and neither does the player feel motivated to proceed.

Overall, the general game's idea is good, but the implementation is full of flaws, be it from the subject specific perspective or the game designer's perspective. The game is not really appropriate for lessons.

5.3.3.3. The Pollination Game

Name: The Pollination Game
Year: 2000
Version: 1.0
Game developer: CARET (Centre for Research in Education and Technology)
Publisher: CARET
Publisher's location: Cambridge, UK
Language(s): English
Platform: web-based

Game's objective:

The goal of The Pollination Game is to design a flower, test it for one of the given pollinators and to earn as many seeds, ergo points, as possible.

Gameplay:

The Pollination Game starts with a quick introduction and the reason this game was developed, namely to understand why many diverse types of flowers exist in nature. The second paragraph provides a few tips for the player:

"*Moths have long tongues so like tubular flowers, and hummingbirds have very long beaks, so like even longer flowers. Birds and butterflies like red but bees can't see it very well. Most animals like lots of nectar, but beetles like pollen to eat too. A strong perfume is important for a flower that attracts night-flying animals, like moths. Bees like nectar guides to help them work out where to land on the flower*."

The second page informs the player about pollination and introduces the processes and elements involved. Once the player is ready they may start the game.

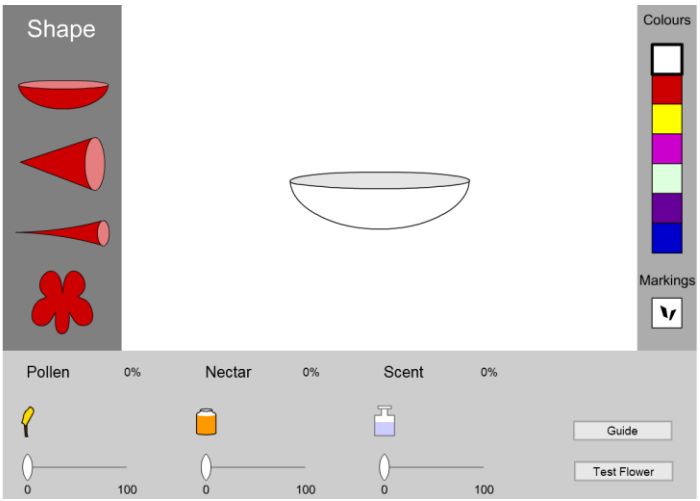

Figure 10: Flower generator (taken from The Pollination Game)

First, the player may create an individual flower in the flower generator. There are four shapes of flowers to choose from: disc flower, two differently shaped tubular flowers and zygomorphic flower. Then the player may choose a colour: white, red, yellow, pink, light green, purple and blue. Furthermore, the flower can have markings, also called nectar guides or not. The player may then decide on a scale from 0 to 100 how many pollen, nectar and scent their flower should have. There is also a guide included, however, it only tells the player which pollinating animals might be chosen in the last step, namely beetle, moth, butterfly, bee or hummingbird. Once a flower is complete, it can be tested for a pollinator.

In the testing phase, the player may not interact but just observe. Five flowers appear, and the chosen pollinator moves over the screen as it "*is on the lookout for food*". If the flower attracts the pollinator the information "*The [X] has spotted a flower and is heading towards it*" and "*starts feeding on the flower"*. After a short while, the duration depends on the amount of pollen and nectar, the pollinator "*has finished feeding and flies off*". This continues for a minute and after that the player gets feedback in the form of seeds that were produced. If, however, the shape of flower is incorrect, but the colour, scent, pollen and nectar amount would usually attract a certain pollinator the player gets the information that the pollinator cannot land on the flower. No points are accumulated. Furthermore, if nothing attracts the pollinator, a minute passes without it sitting down and feeding on a single flower.
The player may try again, but the scores and flower shapes are not saved.

Evaluation:

The developers provide a definition for pollination, namely "… *the transfer of pollen from the stamen to the stigma for sexual reproduction to occur in the formation of seeds. This process is called pollination and is carried out by pollinating animals*." This rather simplified definition may foster misconceptions about pollination insofar as the player might think that the contact of pollen and the stigma represent the sexual reproduction (Lampert, 2012, p. 55 ff.), although the sexual part, the insemination, takes place in the ovule. In addition, the second sentence is problematic as pollination does not necessarily only have to be carried out by a pollinating animal but could also involve other vectors such as wind or water. However, this introductory page, although not flawlessly phrased, already emphasises the most important points: It mentions the parameter which the player may adjust in the game, shape, colour, nectar and pollen and fragrance. Considering the vast variety of adaptations which have developed over the course of evolution, these parameters represent only a fraction of what evolution has come up with. However, these are probably the most important ones and they already facilitate many combinations. Furthermore, the player is introduced to the game's objective, namely designing a flower suitable for one of the given pollinators, enabling it to collect pollen. The flower's mechanism is mentioned, indicating that flower and pollinator must fit together following a key-lock principle.

The editor is simple: Although artistically not very appealing, it serves the purpose and does not overwhelm the player. The "guide", however, is very misleading. The player might think to get further information about the preferences of the pollinators, but instead it is just a picture of the pollinator and their name, without any further hints. It therefore only serves one purpose, namely to tell the player which pollinators they may choose, which could also be displayed in a different way.

The game is very prototypical and lacks fine-tuning, leading to frustrating and misleading experiences. The programmed algorithm allows loop holes which were not intended by the developers. For example, it was found that a flower specifically designed for a bee, with an open flower shape, yellow petals and

nectar, would produce seeds although the parameter for pollen is set to 0. Consequently, this flower should not allocate any seeds as pollination could not take place. In a later experiment it was found that a yellow, zygomorphic flower with 50% nectar and pollen would not attract a bee, because "*it is not the right colour*". If markings were added, then the bee would still not visit the flower. However, once scent was added, the bee could "see" the flowers and would visit them. Therefore, telling the player that the wrong colour was chosen, when the absent scent was the problem is very demotivating and not logical. The programme is full of similar loop holes which not only dim the fun but also lead to further misconceptions and conclusions that players may draw from their game experience.

Testing a flower for a pollinator can be dull, as the player must watch the pollinator moving like a robot for a minute, either visiting flowers or moving around, without pollinating anything. In the end, the player learns for the first time that hat actually counts in the end are seeds, not pollen, and although the first cannot be generated without the latter, this is actually crucial information which should be stated right away. Furthermore, due to a programming mistake the webpage must be refreshed and the whole game started anew, because otherwise the different screens overlap, making playing more difficult.
It is a pity, that the game does not track the player's high score, enabling them to compare themselves with others. A feature, which would not only track the high score but also the chosen combinations of the parameter would make it possible for the player to learn from their mistakes or success and draw conclusions about the already mentioned key-lock-mechanisms of flowers and pollinators.

To sum up, the game is not yet perfect and lacks the precise fine-tuning, but it already offers an interesting approach through the editor and enables discovery learning through trial-and-error. In comparison with most of the other games, it focuses primarily on the flower and not the pollinator.

5.3.3.4. Poliniza

Name: Poliniza
Year: 2017
Version: 1.0
Game developer: FLIP Tecnologias Educacionais
Publisher: FLIP Tecnologias Educacionais
Publisher's location: Goiás, Brazil
Language(s): Portuguese
Platform: Android

As the game is Portuguese and I do not speak this language I made a lot of screenshots and later translated the texts via Google translate. Still, this makes an in-depth analysis impossible, and due to the language barrier, some features of the game may not be entirely understood. However, as it deals with pollination, it is listed here.

Game's objective:

The player controls a bee and has to pollinate flowers in each level to collect nectar (fuel) and pollen before the nectar storage is exhausted. That way the player is able to regrow the forest.

Gameplay:

The game starts with a video introducing the setting. A young boy, Paulinho, returns to his parent's home after a vacation in the capital. However, in his absence the forest was cleared and destroyed. His animal friends want to give up but Paulinho has a plan: he wants to get seeds to plant new trees while his animal companions pollinate the flowers that remain.

Figure 11: Level interface (taken from Poliniza)

The main menu offers the player the option to play a little tutorial or start the game right away. The tutorial explains the controls to the player: in the lower right corner the player has two buttons for "left" and "right" and in the lower left corner two arrow buttons for "up" and "down". In the upper left corner is a red bar indicating the nectar and pollen storage and in the upper right corner a radar map indicates the flowers that need pollination.

The game consists of different levels, with the overall goal to always acquire all pollen there is by simply flying over the flower and waiting for the pollinator to collect the nectar and pollen. The first few levels are played with the bee, followed by a bumblebee and bat (the animal companions of the protagonist). Every pollinator is specialized for certain flowers and not all flowers can be pollinator by one and the same. If the player takes too long and the pollinator runs out of nectar (energy) the pollinator dies and the

player must reattempt the level. The further the level progresses the more difficult the game gets, as enemies such as spiders in spider webs or frogs are in the player's way who needs to evade them. The player may find "golden letters" which can be collected, as there are 14 in the world, and read in the achievement section. They introduce the player to certain fruits and important plants which are relevant to their everyday life, such as tomato or avocado.

Evaluation:

The visual style of the game is appealing and consistent. In general, the game makes a quite well-engineered impression. The background story with Paulinho is a bit stereotypical but at least the game has some context and involves the player emotionally.

The controls are tricky, making it difficult to get close to flowers, which causes the player to waste precious time and often ends in reattempting the level as the player ran out of nectar before collecting the pollen. Furthermore, the orientation with the radar map is rather difficult and not very precise, so the player needs far too long to study the map and figure out where to fly to. However, this also makes it challenging but at the same time frustrating.

Figure 12: Achievement overview showing the amount of flowers and the "golden letters" that have been collected (taken from Poliniza)

As so often, the pollinator is the agent and the centre of attention while the flowers are just passively pollinated. In comparison to other games, this game does not explain pollination and depicts it as the pollinator spending time at a certain flower until all resources are collected, indicated by a fruit falling down. From a botanist perspective this is not very accurate, also because this happens with the first plant of every level as well; however, the first one cannot be successfully pollinated if the pollinator just started collecting pollen, therefore no fruit can develop.

The golden letters are stored in the achievement sections and explain quite thoroughly some botanical content such as common fruits and vegetables. As exemplified by the avocado they not only explain that it is a fruit, but also how it can be prepared and other applications such as using the seed to produce a special purple-brownish paint, or the usage of the bark of the trunk in folk medicine. The texts are rather long but detailed and highly relevant to the player's everyday life.

The game design is well though through and engaging due to the levelling system, the obstacles, and achievements which engage and motivate the player. As mentioned above, the controls are not well implemented and make playing frustrating, but this may vary among players.

Overall, the game is valuable and can also easily be implemented in biology lessons, given that the teaching language is Portuguese.

5.3.3.5. Poliniza Bichos

Name: Poliniza Bichos
Year: 2016
Version: 1.1.
Game developer: RunRana Games
Publisher: RunRana Games
Publisher's location: Talca, Chile
Language(s): Spanish
Platform: mobile (Android and iOS)

Game objective:

According to the developers this side-scroller was developed "to create awareness and promote the biodiversity showing different pollinator insects" (R. Needham, personal correspondence, March 6, 2018). The player's goal is to survive and pollinate as many flowers as possible (=score).

Gameplay:

The player may, first, choose between four different pollinators and difficulties: bumblebee, *Bombus dahlbomii* (easy); honey bee, *Apis mellifera* (medium); hoverflies, *Syrphus* sp. (medium) and a pollinating beetle, *Astylus gayi* (difficult). After one of the four was picked the player gets further information, such as the Latin name of the pollinator and the taxonomic group it belongs to. Moreover, each pollinator has special abilities and resistances; the bumblebee is not only more resistant to birds and frogs but also to the cold compared to the honeybee, which has 'improved speed' instead of the resistance to the cold. The symbols are colour-coded thereby indicating the degree of resistance, which might not be so apparent to the player: red means weak of low resistance, orange medium resistance, blue full resistance or invulnerability and green indicates a positive stat (R. Needham, personal correspondence, March 8, 2018).

Figure 14: Menu Interface showing the four levels of difficulty and pollinators (taken from Poliniza Bichos)

Figure 13: Level interface showing an obstacle (frog) (taken from Poliniza Bichos)

During the game, which was developed for children and therefore uses a simple game mechanic such as tapping on the screen to control the height of the flying pollinators which moves

constantly forward (R. Needham, personal correspondence, March 6, 2018), the player encounters different perils, which must be avoided: mites, wasps, tufted tit-tyrants, swallows, white-crested elaenias, lircay frogs, “rana grande” and, the cold.

The goal is to tap and move over the flowers to pollinate them and increase the player’s health, which is represented by the number of pollinators. The more flowers pollinated, the more speed and health points, represented through the number of pollinators, the player gains. In the end, the number of pollinated flowers represents the end score, which the players may use to compare each other’s performances.

Instead of only four different levels which the player would have to play repeatedly, the level design is always different, probably created through prefabricated elements which are connected randomly.

Evaluation:

The art work is catchy, simple and appealing to children. The developers included typical flowers, predators and geographical landscapes which can be found in Chile (R. Needham, personal correspondence, March 6, 2018). These are the flowers appearing in the game: carob tree, *Puya chilensis*, *Vachellia caven*, *Peumus boldus*, *Lapageria* and “Centella”. The controls are simple and still the game is challenging. Depending on the resistance of the pollinators, fewer die upon contact with an enemy and sometimes the conditions of the world are tricky, but instead of frustrating the player, this encourages them to continue playing.

According to the developer (R. Needham, personal correspondence, March 6, 2018), they wanted to include “casual learning” which they define as “*learning things while you do other things unrelated, in this case you learn about pollination while playing*”. For them the game should teach children the strengths and weaknesses of certain pollinators and lead to realizations such as “*flies are pollinators too*” or “*the [bumblebee] is strong against the cold, but bees aren’t*”. As there have not been any studies conducted we do not know whether children really learn these things.

A biologist might criticise that the same six types of flower are present in every level and pollinated by all pollinators, although in real life they differ significantly in their preferences of colour and flower shape (see syndromes). The player might think that all flowers can be pollinated by all pollinators regardless of the complex co-evolution of flowers and pollinators, which led to very specialized adaptions on both sides. Furthermore, the attributes assigned to the pollinators in the game, such as cold resistance or resistance against certain predators do not represent their real-life attributes. Although they serve an important function in the game, it might send the wrong message and lead to yet more misconceptions about pollination and its agents.

The game design is targeted at rather young players, as the childish and exaggerated art style suggests. Furthermore, it is a bit oversaturated with colours, making it sometimes difficult to see the pollinators. The game includes challenges and special attributes of every pollinator, however, not everything is clear from the in-game explanation. The game mechanics are simple but work and make the game generally comprehensible without long explanations.

To sum up, it is a nice game but not really recommended for school because it is targeted towards younger players and it does not offer much biological content.

6. Result: The Game Design Document

This section presents the game design document. It was decided to apply the structure suggested by Rogers (2010, p. 63ff.), starting with a one-sheet and the ten-pager. As it is uncertain whether or not the game will be developed eventually it makes little sense to get into details regarding, for example, the interface or balancing, as well as the in-depth description required for developers. Still, the GDD includes the most important and basic information, presenting a clearly structured and thought-through game idea with the goal to facilitate student's understanding of co-evolution of plants and pollinators, for this is the focus of the game.

Finding an appropriate writing style for the GDD was difficult, as on the one hand, it would be part of an academic paper, which would require it to adhere to high language and academic standards. On the other hand, a GDD is usually written for potential publishers or sponsors and in this case the target group is a game developer studio or even an educational institute. Therefore, the GDD needs to be engaging and a bit advertising to persuade the target group, which is why it was chosen to apply a more informal writing style which addresses the reader directly. Moreover, the final GDD should be a stand-alone document, which works not only within the context of this thesis but on its own as well.

I wanted to make a fun video game, which manages to include and represent the biological content in a subtle way. The students should not be negatively biased towards the game because it is a "learning game", but discover later, while playing, that it conveys interdisciplinary and evolutional processes in flowers and pollinators. Furthermore, I wanted to achieve more than a simple learningapps.org[24] application. However, it soon became clear that only certain content lends itself to be implemented in a digital game, given the possibilities and resources. Every animation takes a lot of time and skill to produce, which is why it was decided to make a 2D game with only comic-like cutscenes in-between. Marie-Theres Pekny provided some concept art, alongside my own sketches to better demonstrate and convey the style and feeling of the game.

The following GDD for "EvoFlo" is the final version, which was preceded by many smaller and less precise drafts, which will be attached in the appendix. "EvoFlo" is a combination of "evolution" and "flora", and it was chosen because it is short and easy to remember.

[24] https://learningapps.org/ (31.05.2018)

6.1. Final version of the game concept

There is not one universal way of writing a game concept but the one-sheet and ten-pager are precise and practical enough to be integrated in a diploma thesis. The following is the final version of the game concept, which could be taken from this thesis as it is and shown to a game developer or educator for further development. The draft also includes concept art for artists.

6.1.1. One-sheet

EvoFlo

6.1.1.1. Intended game systems

The game will be developed for PC and mobile devices, including iOS and Android smartphones and tablets. As most schools are equipped with PCs it makes sense to develop for PC and given that the equipment may not be the latest and the fact that students have smartphones and/or tablets it stands to reason to optimize for Android as well.

6.1.1.2. The players

The game is targeted towards 11year olds and up, as the topic of pollinations is part of the Biology curriculum in the first class of secondary school in Austria. It is assumed that the target group has some experience with video games, the controls and mechanics. The game is not intended to be a substitute but a supplement for teaching pollination biology. However, as no prior knowledge is needed and as the game can be a stand-alone, it can be played at home and by adults as well, who are into strategy games.

6.1.1.3. PEGI rating

PEGI 3: The game should not contain any content that is in any way or form inappropriate for children of any ages.

6.1.1.4. Summary of the game's story focusing on gameplay

2095. Mankind has developed ways to inhabit other planets through terraforming. The first one is Mars. A group of scientists leaves earth to travel to this neighbouring planet. Among them are zoologists, geologists and you, a botanist. Once you arrive at the research station you get to work immediately. Your task is to fill the landscapes, which was designed by the geologists and the pollinators created by the zoologists, with flowers. From the desert to the tundra, over meadows and plains to an alpine mountain area or the forest- every landscape wants to flourish. Each area consists of a several levels, each featuring new challenges to overcome. Players will have to cover the whole planet with their creations and can unlock new areas by completing challenges in the previous ones.

6.1.1.5. Distinct modes of gameplay

The player proceeds from one level to the next, progressing via unlocking new landscapes and flower traits, however, with the possibility to always go back to the research station to read up in the glossary or try out different combinations in the trail zone. Each level consists of two phases, the planning phase with the plant editor and the execution phase, simulating how well the new flower copes with the conditions. The player faces numerous challenges through the unique combination of area-specific conditions. The player sees the conditions at the beginning of the level and may edit the flower (within a certain budget) and may then test and simulate the execution. The player cannot interact during the execution phase. Every level unlocks new and more specialised features for the editor, but still, the player must budget their resources well, as their choices are limited because some modifications are more expensive than others. A special reward system grants the player 0 to 3 bonus points for each level, depending on how well the flower is adapted to the conditions. These bonus points are accumulated outside of the levels and maybe used to unlock bonus levels or areas or buy special items for their avatar.

6.1.1.6. Unique selling points

- Explore and help to shape a new planet
- Test your designing skills
- Unlock bonus levels
- Watch your creations flourish

6.1.2. Ten-pager

6.1.2.1. Title page

Figure 15: Logo of EvoFlo (Bernadette S. Auberger)

Intended game systems	PC, Android
Target age of players	11+ years
PEGI	3
Projected ship date	/

6.1.2.2. Game story and game flow

2095. Mankind has developed ways to inhabit other planets through terraforming. Still, not every planet lends itself to be transformed easily and without great costs, but they don't give up and finally manage to transform Mars. A group of scientists readies themselves to leave earth and travel to this faraway new land. Among them are the best scientists from around the world and especially zoologists, geologists and you, a botanist. This first scene is an introduction in form of a comic with a speaker describing the scenario and setting the mood. Everything else follows is in 2D. Once you arrive at the research station, Dr. Lauren, the head-researcher at the bases, welcomes you, shows you your room and explains the editor to you. After the tutorial you can get to work immediately.

Your task is to fill the landscapes, which were designed by the geologists, with flowers. You will be working with the zoologists as well, who create different pollinators for your flowers. The research station is the start point of you journey. The first adjacent area is a simple meadow and you will start with very basic flowers, which are pollinated by the wind. Each area consists of four levels but simply playing through them will not automatically unlock the next area, but you need to accumulate at least 9 from 12 possible bonus points to reveal the next area, which will be the forest. After forest, the next area features pastures at a higher altitude and the last is an alpine mountain area. Two bonus areas, a lake and meadows which are occasionally flooded, with one level each can be unlocked during the game.

Each level has different theme or problem. For example, Bill, one of the zoologists, messed up and now one of his pollinators is loose which wasn't properly optimized yet: it is a bee-like creature, rather careless and big, with hair only on its head for pollen to stick to. He can't remember which colour it is supposed to be attracted to but trusts in you to find out. This information tells you to pick a shape of flower, which allows the pollinator to crawl in, provide longish stamen which touch its head and the petals need to be rather sturdy to withstand the rough behaviour. Other challenges might be difficult conditions, such as very high or low temperature, humidity, or mechanical factors such as wind or water. Furthermore, the flower must be resistant to enemies, parasites or may have a vicious competitor, which forces you to specialize your flower further.

If the last level is completed successfully you will have reached the end of your mission, congratulations! The areas flourish now with your new creations. You have unlocked all possible traits for the editor and may revisit the trail zone to try out different combinations without the budget restrictions and save your designs to compare with other players. If you're up for a challenge then you can also try out the advanced strategy mode, where the conditions are randomly mixed and where you are once again in charge of your budget.

6.1.2.3. Characters

The characters only appear in dialogues and only their portrait it visible in 2D on the right side of the screen, while on the left side the player's portrait is shown. There need to be different emotions to make the text-based dialogues better by conveying the general mood. The text is not synchronized by actual speakers but rather a dummy language, like in The Sims-series, is used.

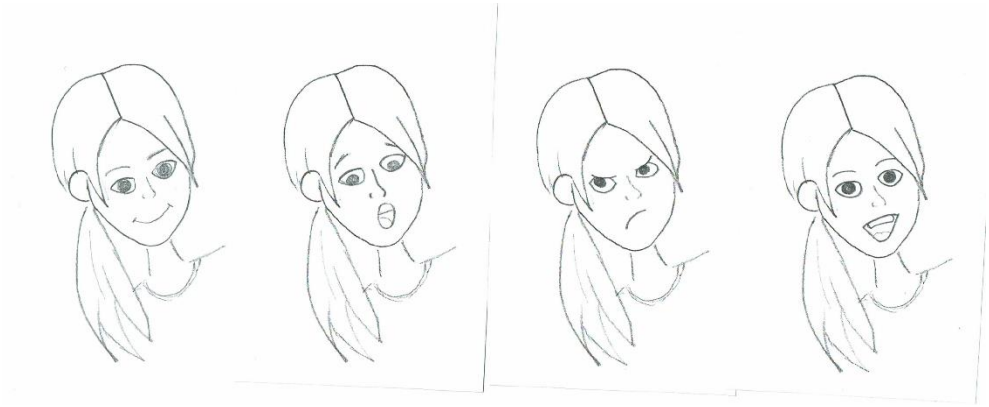

Figure 16: Concept for NPC's showing emotions such as friendly, alarmed, angry and very happy. (Bernadette S. Auberger)

Dr. Lauren is a young, ambitious scientist and head of the research team at Mars. Against the stereotype of scientists being old, men with white hair, beard and glasses wearing a white coat, a young woman was chosen to guide the player through the game. She has brown eyes and hair, which she wears as a ponytail. Her skin is a bit darker and overall, she should not look too "Caucasian". As only her portrait will be visible in the game the rest does not need to be more defined. She welcomes the player to the research station and explains all the tools in their room to them, such as their diary, which functions as a glossary for the traits and also saves their designs, or a wardrobe which enables the player to customize their avatar. Dr. Lauren will be explaining in small sequences the basic nature of each area and will mostly tell the player their goal for the different levels. She might also give hints if the player wishes her to do so, or they may dismiss the hints altogether.

Thomas is one of the geologists that arrived with the same shuttle as the player, so he is also new to the research station. He is a bit chubbier, has short curly hair, a full beard and glasses. He may appear before a level to describe the challenge of this level concerning the geographical conditions.

Cassandra is a zoologist, which often works in the same area as the player does. She is Asian, with black hair and dark eyes and a rounder face. She gives the player information in the beginning of a level and explains whether there are any specialities concerning the pollinators or the rest of the fauna she designed. Cassandra happens to be good but under pressure a small mistake might occur, and she needs the players help. Also, after a level was successfully mastered she might praise the player and encourage them to go on or offer a hint occasionally.
Bill, is a zoologist as well and already in his forties. He is dark-skinned and athletic. He has a quite similar role to Cassandra and may state missions for the particular level or give feedback.

The player can create an **avatar** at the beginning of the game to individualize their game experience. The simple editor lets them choose the gender (male/female), skin tone (five shades from fair to dark), colour of the eyes (brown, blue, green, grey), hairstyle (short, bob, ponytail, …) and hair colour (red, brown, black, blond). More features will be unlocked the further the player progresses, and they may then equip their avatar with scientific objects, such as glasses, a beige polo shirt or fun objects such as funny hats (explorer's hat).

6.1.2.4. Gameplay

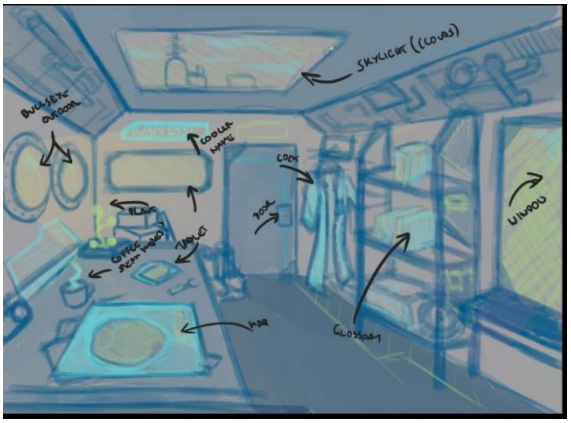

Figure 17: Interface "research station" (credit to Marie-Theres Pekny)

Once the player starts the game for the first time, rather than continue from a save point a short cut scene explains the background story and shows how the scientists take off and arrive on the new planet. The main interface is featuring various possibilities for the player is their room at the research station, basically a container (see fig.2). By clicking on the objects, the player enters a new "room". The map leads to the level overview (see fig. 3) and therefore the actual game. The books open the glossary, where new entries are added once the player has unlocked them. The tablet enters the trail mode, which can be accessed always, allowing the player to design flowers without any restrictions and to their liking. The door leads back to the main menu.

The player starts the game, clicks on 'play' and 'start new game', or 'continue' if a save game exists. The 'research station' interface appears as does Dr. Lauren and a speech bubble in the lower corner. She explains the controls of this interface: "Here you can enter the glossary" or "This will lead you to the levels". She will also guide the player through a tutorial explaining the level interface and features. Once the players have familiarized themselves and decided to turn to the level overview, Mars appears and by clicking on the zones the player zooms in and may select a level. After a level was mastered successfully, the newly designed flowers appear in the zone, gradually filling the landscape with new species. The player enters a level and is shown the conditions (i.e. wind, bee-like pollinator, …) of this level in form of icons which reveal a brief description if the player clicks on them and then the planning phase starts.

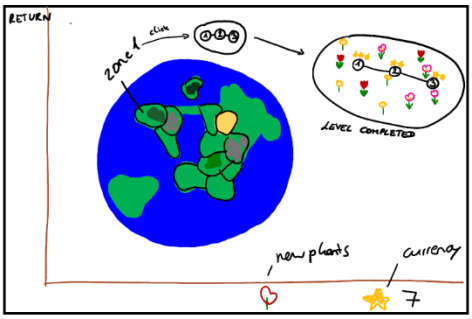

Figure 18: Level overview featuring the new planet (Bernadette S. Auberger)

A dropdown menu on the left shows possible traits (see fig. 4), which can be modified, and which will grow over time as the player unlocks new ones. Each trait has a value and the player may have a budget of 2000 $ to spend on this design. 'Play' starts the action phase where the life cycle of the plant is simulated over a whole year. The animation features the conditions, possible pollinators which might be attracted or not and in the end the amount of produced seeds gives the player feedback on their performance, and 0 to 3 bonus points ('currency') can be received.

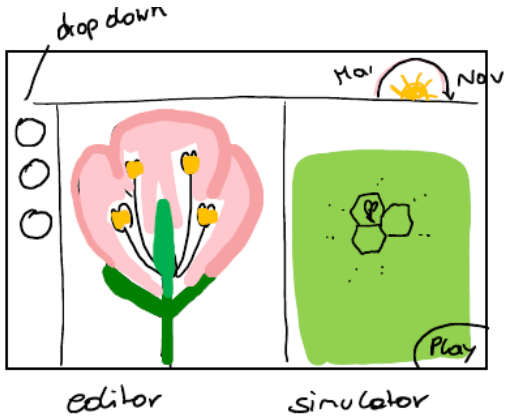

Figure 19: Level design, editor (left) and simulation (right). (Bernadette S. Auberger)

The game continues, and the player faces different challenges, unlocking new areas with specialized realistic conditions, may spend their bonus points on extra-levels or individualize their avatar until they have finally reached the end and completed the task of designing new flowers, making the planet ready and inhabitable. It ends with a cutscene, in 2D comic style the shuttles of new inhabitants arrive on Mars.

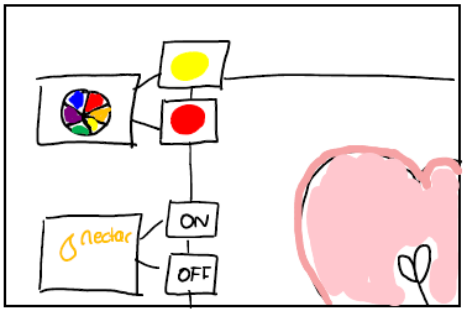

Figure 20 Close-up of the dropdown menu of the editor (Bernadette S. Auberger)

6.1.2.5. Game world

The game is set in a low sci-fi setting and in the future, around 2095. Humans have found ways to inhabit other planets due to overpopulation. They found Mars, a planet with similar conditions to earth and after a bit of terraforming and establishing ecosystems it would be ready for the new settlers. After the terraforming is finished a group of scientists arrives to create fauna and flora for the landscapes, which can vary from the ones on earth, but in general it should resemble earth making it easier for the inhabitants to feel comfortable and at home.

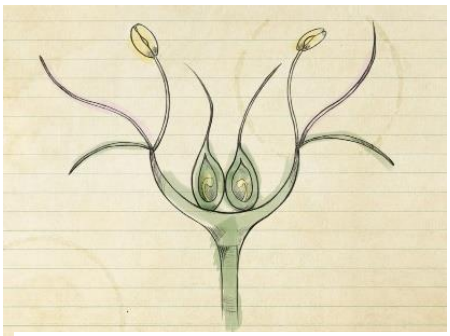

Figure 21: Concept art for the editor (credit to Marie-Theres Pekny)

As the concept art (see fig. XY and Z) suggests the style of the game is a mixture of modern elements (tablet and digital map) in combination with typical "old-school" gadget from the 20th century (radio). Furthermore, the colour scheme in beige and rather subdued colours is known as researcher stereotype of the last century, taking notes and drawing in their journals and wore beige clothes when in the field. This game tries to capture this romantic perspective rather than picturing a sterile laboratory where everything is white, and people only wear laboratory coats.

Figure 22: Concept art for the table in the players room at the research station (credit to Marie-Theres Pekny)

The world in general looks similar to earth, but the continents are distributed differently. On the level overview map the player sees their starting position, the research station, interconnected containers where the scientists take up residence. The research station is further inland, and the landscapes are all similar to Austrian ones. Adjacent is area 1, the meadows. The climate is mild and the grass is very fresh and green. While playing level 1-4 the right screen shows the meadows with hexagonal fields on it and the player may observe the change during the simulation of a one-year life cycle of the flower they designed. The background music is soft, light and cheerful.

The second area is a typical mixed forest, with less light and more specific habitats and new competitors such as bigger plants, different wildlife and pollinators. The forest is more mysterious which mirrors in the background music.

Area 3 features typical Austrian pastures on a higher altitude. Here the ground is rockier, and summers are much shorter. The pollinators are highly specified, and the plants rely a lot on them. Here the music is again a bit lighter.

The last landscape are alpine mountains, a very special and unique landscape with an astonishing ecosystem. The conditions are much rougher, but plants have found ways to cope with the frost and winters. Here the music is rather tumultuous, and the next sequence may be cheerful, mirroring that the atmosphere changes quickly in the mountains and storms or rainfall are more extreme than further down in the valley. The player should really grasp these landscapes in their entirety, associating with it and establishing a bond with nature and its inhabitants.

6.1.2.6. Game experience

As described above in the game world section the game tries to convey on the one hand a romantic 20th century scientist feeling and on the other hand superior technology and possibilities to what we can do today. The player should feel secure, at home and enjoy the nostalgic and decelerated atmosphere.
The player is engaged through a rewarding level system, with achievements to be unlocked as well as bonus levels. The goal is clear, and the designing and modelling aspect is highly engaging as well as motivating.
This game builds on a rather complex biological topic, namely pollination and the co-evolution of flowers and pollinators. The players are supposed to learn intrinsically about the underlying concepts and relations of all the features of flowers which go hand in hand. This subtle learning can help students to theorize and hypothesise on their own and try out in a safe sandbox environment coming to their own conclusions.
The intent is to engage the player in a playful and fun way, and to evoke positive emotion in relation with a complex topic such as flower ecology.

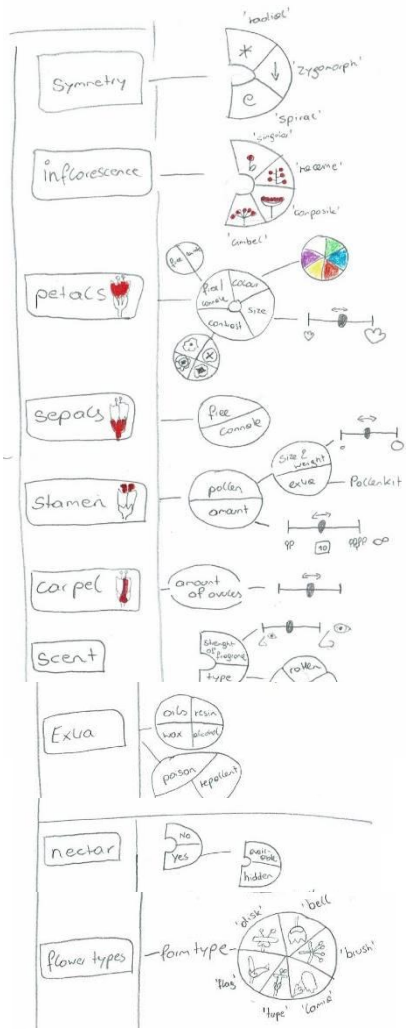

Figure 23: Draft for the dropdown menu (Bernadette S. Auberger)

6.1.2.7. Game mechanics

The main mechanics in the game concern the editor, where new flowers are generated. The generator offers a dropdown menu on the left which the different features and traits that can be added to the flower via simply "clicking" (activating and deactivating), via "scrolling" (through the dropdown menu of the editor) via "adjusting a bar" (increasing from left to right or down to up) or by "dragging and dropping" a trait onto the model.
The player may click to reveal the dropdown menu in the editor and scroll through it. By clicking on one trait further options to adjust this feature are revealed. First the player only sees the column with the overview terms, such as 'flower types', 'symmetry', etc. If the player clicks for example on flower types, a circle appears where they may choose from among the given simplified types as a starting point for their new flower. Note all options depicted in figure XY are available from the start. Most of them will be unlocked step-by-step to gradually make the player familiar with their function and the terminology. Sometimes the player needs to regulate a bar, as is the case for the size of petals, the amount of stamen or the strength of fragrance of the scent. Some decisions on the top may automatically disable features below because certain combinations just don't work (i.e. flower type "flag" eliminates the 'radial' and 'spiral' symmetry option).
By holding over one of the traits such as the symmetry, the player gets further information, namely what is meant here. The same works for the different variations such as '*' which could tell the player that the radial symmetry comes with certain attributes. To not overwhelm the player with too much text, this information is brief and precise, often in form of bullet points while a more elaborated explanation can be found in the glossary at the research station.
Traits which were added after the draft was completed are the 'shape' and the 'number' of petals. The player can select both in the menu by clicking on the icon but may drag and adjust on the model itself to model and arrange the flower by shaping the petals.

Each trait comes with an information concerning its price, the amount of money that needs to be invested to realize that trait. Examples for balancing:

- Single coloured petals are cheaper than two-coloured ones which attract some types of pollinators even better through the contrasting colours.
- A certain pollinator may rely a lot on a rotten smell but have no visual preferences, so the player may choose to design rather basic petals and invest the budget elsewhere.
- A flower which is pollinated by wind does not need to invest in attractive petals but should rather produce a lot of light pollen which can be transported over longer distances.
- If a pollinator is said to be reckless, often destroying fragile flowers, the player should choose to connate the sepals and petals which adds to their stability.
- A bee-like pollinator may already be attracted by the right colour, but even more would visit the flower if it had markings as well or nectar.

The player needs to find the right balance between many factors which are interwoven with each other. Every action has consequences.

6.1.2.8. Enemies

In EvoFlo there are not enemies per se, but different conditions which shape the levels. They determine the difficulty and give the player a direction while designing their flower. This process should enable the player to see the relationship between the different traits and how certain combinations work well together, as they do in real life. However, there is not only one correct solution but several that should come close.
The conditions, which may not all influence the design of the flower but the whole plant, can be categorized as biotic factors and abiotic factors. Biotic factors include food/nutrition availability, competitors (occupying a certain niche), enemies (animals that forage on that plant), parasites and pathogens, symbiosis which a specialized partner plant, and different pollinators. Abiotic factors include temperature, humidity, rainfall, fire or frost, specific soil conditions, such as chemical factors (CO_2, O_2, pH), wind, water, light, special climate with heat or drought.
These conditions are featured at the beginning of each level as icons with easily recognizable symbols. By clicking on them the name is shown and two to three bullet points explaining them. However, every time a new condition pops up in the game it is automatically entered to the player's glossary where they can read up on it, understanding them better and to get further information. These conditions shape every level and are the basis of level design.

Here is an example of the level design for the first four levels in the meadows:

Area	Level	Condition	Reward Trait	Solution
Meadows	1	Wind, open landscape → pollen can travel far,	Sticky stigma Raceme	• Colour of petals = white = cheapest • Small petal shape • Small, light pollen • A lot of pollen • Tall style with large stigma
Meadows	2	Wind, open landscape, more flowers and increased chances of pollen to get to the stigma	Petals (free, connate) Sepals (connate)	• Colour of petal = white • Raceme inflorescence • Small, light pollen • Tall style with large sticky stigma
Meadows	3	Wind + pollinator (beetle-like): flower bust be sturdier, preference for more colour,	Scent (rotten and fresh) Petal form (sturdy)	• Connate sepals • Colour (white-yellow-orange= okay to best) • A lot of pollen • Light pollen
Meadows	4	Pollinator (beetle-like): feasts on pollen, reckless, colour vision, nice scent		• Sturdy petal form • Connate petals and sepals • A lot of pollen • Fresh scent

Table: Example for level design of the first three levels for EvoFlo (Bernadette S. Auberger)

6.1.2.9. Cutscenes

The following are all sequences which are non-interactive and, therefore, break up the gameplay.
The introduction video is a series of scenes explaining the background story, mankind discovering planets and terraforming, showing the shuttle with scientists leaving for Mars, the new planet, technically inhabitable but the scientists want to introduce specialized fauna and flora. Designing the latter will be the player's task. The sequence is full screen, with a speaker talking while showing the subtitles simultaneously in the lower middle section. It can be skipped by clicking on the skip button in the lower right corner.
The video sequence in the end applies the same style. It shows the celebrations of finally finishing the design and implementation process, the now flourishing landscapes and new inhabitants which arrive in the first shuttles to take up residence in their new home on Mars. This sequence is followed by the credits.
While playing, the NPC's and often quest givers interact with the player, depicting their portrait in the right lower corner and in the middle is the speech bubble with the text with and the player's avatar on the left. These are merely instructions and hardly ever give the player the opportunity to reply. The player can forward the dialogues according to their pace of reading by simply clicking on the arrow button on right. Not every level starts off with a dialogue but those with special challenges do.
These dialogues appear during the tutorial, at the beginning of a level or at the end to congratulate the player when an achievement was unlocked or in-between to give further hints and explain newly unlocked features during the game.
In addition to the dialogues, there are instructions in the footer at the beginning of each level. These are simply text-based.
The second phase of each level, which is basically a simulation also offers no interactivity apart from allowing the player to attempt a retry immediately if their designed flower could not withstand the conditions. These simulations should only take 10-15 seconds to not bore the player.

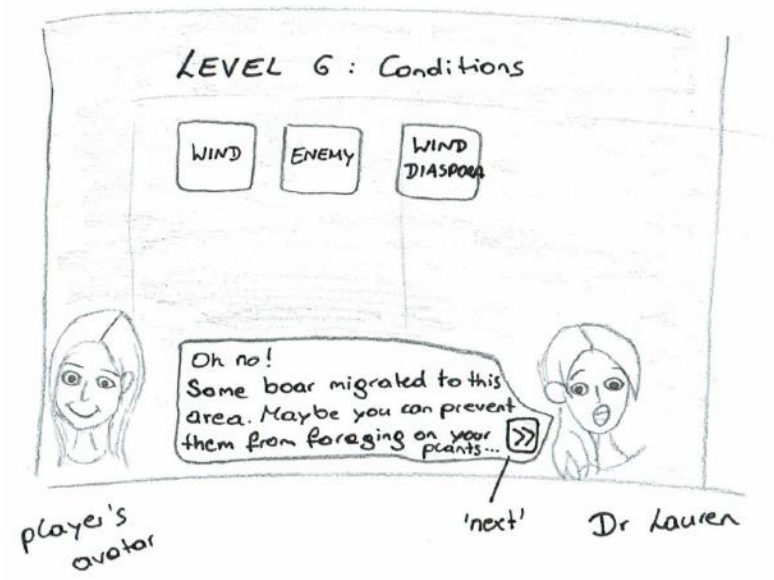

Figure 24: Example of the text-based dialogue at the beginning of a level. (Bernadette S. Auberger)

6.1.2.10. Bonus material

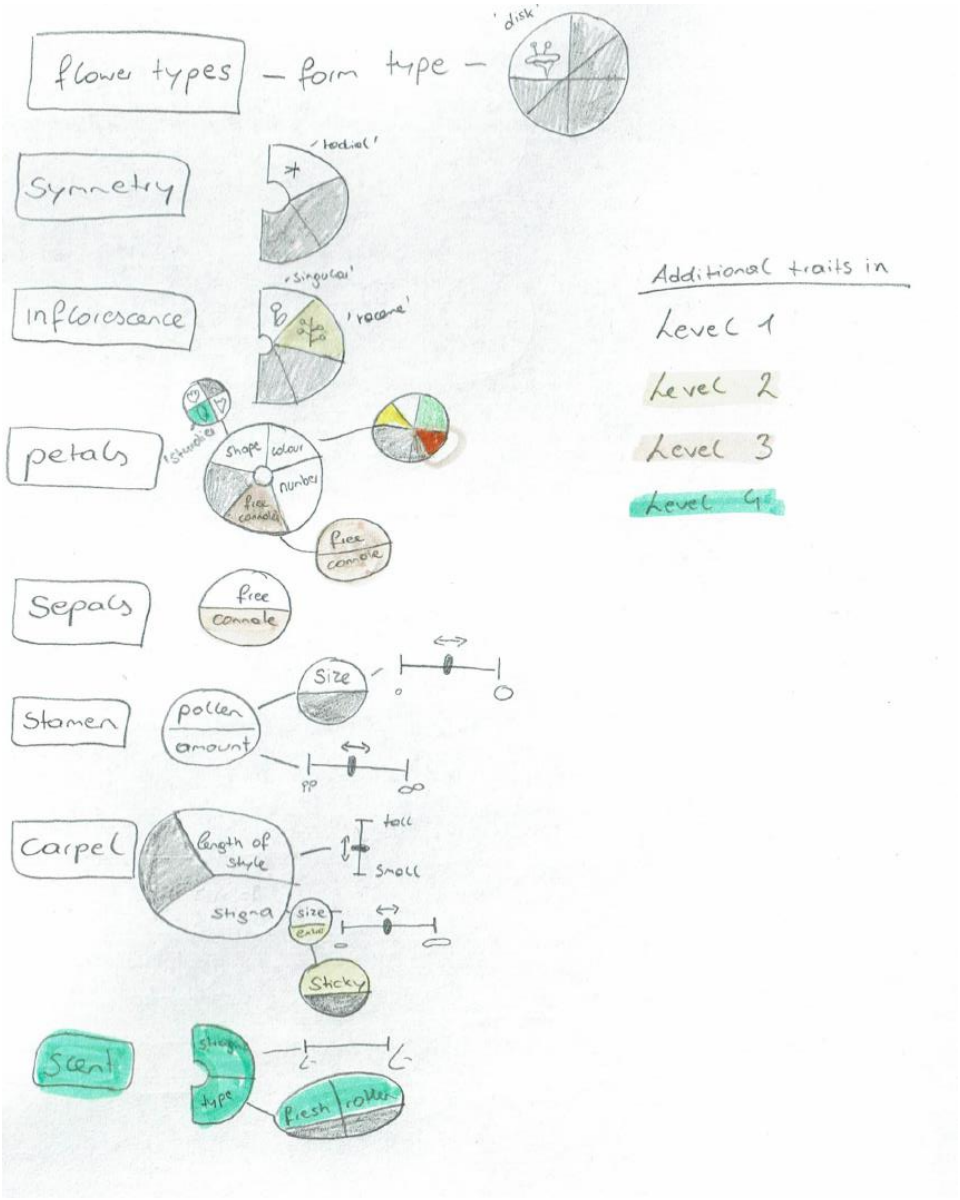

Figure 25: Dropdown menu of the editor for level 1-4; yellow coloured items are unlocked after level 1, orange ones after level 2 and green ones after level 3. (Bernadette S. Auberger)

7. Discussion

As this is the first thesis on the Subject Didactics Institute for Science Education of the University of Vienna (AECC), it gives a broad overview of related fields and terminology and forms the basis for further research. The original proposal for this thesis, to not only present a GDD but also a digital prototype, was too ambitious. Although a friend would have suggested to program a prototype free of charge and another friend offered to make the graphic works, time was in the end the limiting factor. Furthermore, the theoretical part on video game studies and the use of video games in the classroom proved to be overwhelming, given the interdisciplinary nature of video game studies and the inconsistency in terminology and the weaknesses in the body of research concerning the positive effects of video games. Another limiting factor was the availability of play testers of the intended target group. A new law makes it considerably more difficult for teacher students to work with children in schools for their research purposes and many teachers declined fearing the bureaucratic and administrative burden of organizing playtest session or even brainstorming ideas with the students to tailor the game to their needs and expectations. This violates one of the most important game design principles, namely "playtesting from the very beginning", which is why it neither can it be claimed that the game concept is appealing to the target group, nor can it be certain that the game supports the learning goals and outcomes, such as conceptual understanding, as was intended.
Another difficulty was the popular science nature of the topic "games in education" and game design in general. Finding common ground between academic texts and popular science is not easy, however the latter one is often more practical and delivers important insights from professionals, which is why their opinion should not be neglected.

Future outlook for this thesis would be the actual realization of the game, incorporating it in the curriculum and lesson plans and testing it. It can be said that games have a potential to be integrated as teaching tools, given that the parameters and the setting are established well. In order to study their use the experimental and control setting must be set up in a way that as many external factors as possible are excluded in order to come to reliable and valid conclusions.

Given that the scientific interest in that topic is increasing and new papers published every week, it is suggested that Austria, as well as the tertiary education sector turns its attention to this field and invests in the steady research, development and teacher training to equip the new teacher generation with the necessary tools to deal with the growing technological advances and challenges. It is apparent that a new approach is needed to counteract the disinterest of young people in science and to show them the relevance of science for their daily lives. Incorporating video games will not the only solution to this, but it may be part of it.

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