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Development of a Design Tool for Biologically Inspired Fault Adaptive Design by Strategy Mapping

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By

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Abstract

A design tool for Biologically Inspired Fault Adaption that utilizes the concept of strategy mapping was developed and the development process and testing is presented in this paper. The concept of strategy mapping is derived primarily from the field of military theory and supposes that for any given specific problem, that there exists a specific solution for, a single strategy can be identified for that solution/problem combination. This strategy, when applied to the specific problem yields the specific solution. This specific solution is referred to as the "tactics" of the strategy. The strategy can also be directly applied to a different specific problem which yields a different specific solution to the different specific problem. This concept is developed and applied to Biologically Inspired Design and uses biological analogs as the tactics for whatever design problem is being addressed in nature. A library of over 180 biological analogs that exhibit fault adaptive behavior was developed and for each analog the corresponding strategy was identified and cataloged in a design tool. The design tool uses a series of binary questions relating to the design problem to guide designers to the strategy that would have been exhibited in nature for their design problem. The tool also provides one or more example analogs of that strategy being implemented in nature for use as a direct inspiration and to see the strategy in action. This design tool was then tested using 11 groups of design students randomly assigned a design tool for biologically Inspirited Design of which were AskNature, The Strategy Mapping Tool and a generic internet search engine. The results were then compared against each other and from this the design tool using Strategy Mapping showed several clear advantages over competing design tools.

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List of Published Papers

Huisman, N., Jensen, D., "Biologically Inspired Design Tool by Strategy Mapping." American Society of Mechanical Engineers Journal of Mechanical Design
(In Review)

Huisman, N., Jensen, D., "Validation of a Biologically Inspired Design Tool by Strategy Mapping." American Society of Mechanical Engineers Journal of Mechanical Design
(In Review)

Introduction

The goal of this research has been to develop a tool to assist in integrating Biologically Inspired Design into the area of Fault Adaption. The problem that has been typically encountered in Biological Inspired Design (BID) in general is the difference between the mechanisms and processes used by nature and by engineers. This difference causes problems in selecting and applying specific biological analogs to specific engineering problems because cellular action and neurological processes, among other things, have no direct analog in engineering. Research into this area has primarily been focused on attempting to better locate analogs that can be easily applied or attempting to abstract the concept so it is sufficiently general as to apply to the engineering problem trying to be solved. The concept of Strategy Mapping, as introduced in this work, attempts to bridge that gap by instead concentrating on the strategy behind an analog. This allows for a strategy to be defined that can be applied to nearly any design problem independent of the exact circumstances. This approach is applied specifically to fault adaptive design because fault adaptive design has almost been left untouched by Biologically Inspired Design researchers. This is likely due to the previously mentioned differences in mechanisms used in nature and engineering which makes a more traditional BID approach more difficult.

This work is presented as a combination of publications because this work can easily be divided into several sections and it was determined that these sections would correspond to publications in major design journals. The first section will cover the development of the design tool including an in-depth review of the supporting literature and full introduction to the final design tool iteration. The second publication details how the design tool was tested. The test was performed as a comparison study which compares the Strategy Mapping Tool to AskNature and compared the results of student design groups using those methods.

Biologically Inspired Design Tool by Strategy Mapping

ABSTRACT

Fault adaptive design seeks to find the principles and properties that enable robustness and implement those into engineering products. In nature, this characteristic of adaptability is the fundamental trait that enables survival. In this work we explore two fields, fault adaption and bio-inspired design, and discuss a major issue in connecting them. Specifically, we present an ongoing effort to develop a design tool that will bridge the gap between these two fields. The design tool uses a method called Strategy Mapping to identify an overarching plan behind natural solutions for fault adaptive problems. The tool is organized as a tree that consists of paths and nodes that designers move between. At each node the designer is presented with a binary question indicating which direction to proceed within the tool. This tool presents abstract strategies of a specific problem solved in nature, in addition to examples of solutions utilizing those strategies. The abstract strategy allows designers to use natural solutions from biological analogs even though those particular solutions may be directly applicable to the current design. The designers can create a design that uses nature's strategy instead of mimicking specific examples. This work supports a broader effort to identify ways that engineered systems can improve fault robustness inspired by natural analogs.

INTRODUCTION

Every natural organism and system displays some remarkable adaptive trait. The natural process of selection automatically filters poorly adaptive organisms. Since successful models of adaption

to environmental changes and uncertainties exist in nature it is important that engineers look to these and identify if anything can be learned to develop robust systems. The area of adaptive design research is focused on identifying the specific methods and properties which enable an engineered system to continue to provide functionality in the presence of external or internal faults [1,2].

There currently exists an issue in connecting fault adaptive design and bio-inspired design. That issue is the difficulty in applying natural solutions directly to engineering problems which stems from the difficulty in applying the mechanisms utilized in nature to engineering problems. The implementation of robustness and adaptability requires a more complicated approach than the use of an analog from bio-inspired design. This is compounded by many biological analogs using chemical processes that are not readily available to engineers. This paper will attempt to bridge these two areas with a tool that a designer can use throughout the design process. This tool is developed based on a novel approach to design by analogy. In most biologically inspired design methods and tools the objective is to identify natural functions and structures and implement those in engineered systems. In this research we explore how to relate the natural *strategies* of adaption to implement fault adaptive design. The key differences between this approach and the analog search methods are that the designer does not need detailed information about the system being designed, simply a basic understanding of the process. Second, the specific mechanisms utilized in the analog are not used in the design tool.

The tool presented in this paper is based on the use-case of a designer identifying potential natural solutions that enable more robust performance. That is, a particular fault is of concern and needs to be addressed or there is a desire to generally provide more tolerance to unanticipated failures. This work builds on ontological design by analogy. However, instead of

keywords, it presents a series of binary questions that advance the designer through the applicability of the analog. These questions are about the system being designed and what the system is intended to do. For example a question may be “Does the adaptation minimizes down time for the system?” The answers are either yes or no and each will lead to a new binary question. The tool will ultimately lead to a category containing one or more biological examples of fault adaption.

Designers begin at the top of the tool and work their way out by answering the binary questions based off of the design they have or wish to pursue. This allows designers to see potential paths they can follow which lead to different analogs and show different ways fault adaption is exhibited in nature. Designers can use this to check if natural solutions exist similar to their project, potentially saving time if the answer is no, and also have the flexibility to easily investigate other methodologies for solving the problem by changing the answers to the binary questions.

The most important aspect of this tool is not the analogs it provides but the answers to the binary questions. This shows the *strategy* behind the solution and not just the solutions. Most research in bio-inspired design is built around finding suitable analogs for a problem and thus only provides how a similar problem was solved in nature. The novel contribution of this approach is to explore how the exact problem would be solved in nature by identifying the strategy.

In the following sections we review related biologically-inspired design methodologies and review the supporting concepts in the fields of military theory and business management. Based on this background we present the concept of strategy and tactics to address this unique type of engineering problem. The fault adaption Strategy Mapping Tool is built on this theoretical

construct and will be discussed with some examples of the biological fault adaptive strategies. We will then conclude with some closing remarks and a summary of future work.

BACKGROUND

Biologically Inspired Design

There are many examples of designers implementing successful analogs of functions and structures in nature and using them to create novel technologies such as Gecko Tape and the Roboraven [15,16]. Further, design researchers have identified successful ways to implement biologically inspired design (BID) in terms of the design process [3,4,5], analogs storage and representation [6,7], and identifying successes [8,9,10,11]. Existing bio-inspired design tools can be broadly divided into two categories, functional and principle. Functional design tools search the functions of analogs to try and match those analogs up to problems in the design world. These methods may modify the analog or the problem via abstraction to try and bridge the gap between the different mechanisms used in nature and in mechanical design such as the 4-Box method [12] and Biocards [13]. The second group searches based off of the principles seen in those analogs, for example Bio-Triz [14].

Several challenges of bio-inspired design have been identified in research [17]. The first is the difference between scale of nature and engineering problems. Nature works on a microscopic level while engineering works on a macroscopic level and this has caused issues with connecting the two fields. This work addresses this by taking the specific circumstances out of the problem. This allows the designer to use principles seen at the microscopic level for macroscopic

applications. The second major challenge is that nature uses a fundamentally different set of mechanisms than engineering. Nature uses cellular action while engineers use Newtonian physics to solve problems.

Bio-inspired design uses nature to provide examples of systems which are then used as analogs for engineering design solutions [5]. The primary method involves selecting a biological analog and then creating a solution based off of it. There are many databases of biological systems from an engineering perspective such as AskNature [15] and these, when used in conjunction with some processes, allow engineers to determine suitable biological analogs for many problems. Most of the research in this field is related to materials and nanoscale structures however, more work is being done on large-scale systems. For example an adhesive that mimics the hair on the feet of geckos was developed [16] while the University of Maryland used the natural movement of bird wings to create a drone that flaps its wings to generate lift and thrust [17]. The challenges of this field are the fact that biological analogs are used which do not directly relate to engineering solutions. Another challenge is that there is no easy way for engineers to adapt the problem definition during the search process to allow for greater flexibility in solutions. A problem is stated and an analog is searched for that problem without much consideration given to whether or not the problem can be modified to find a better analog and therefore a better solution**.**

After reviewing these two methods we now point out that the fundamental difference between the traditional Bio-Inspired Design approach and the approach considered in this work is that functional abstractions use the specific functions, principles and behaviors of the biological analog directly to assist in design whereas this work does not. This work also does not aim to provide a biological analog to a problem but does so as a consequence of the process it uses. The

key difference between function and strategy is that function only considers what is being done whereas strategy considers the principles, concepts and decision making trends by which that function was chosen for the specific problem. The approach considered in this work uses the specific functions to determine strategies and principles. While the analogs the design tool provides may be useful as inspiration for specific solutions, the goal of the approach presented is to present the designer with the concepts and the plan behind the specific analog. Existing methods will change the functions and behaviors of an analog into forms that can be directly applied to mechanical systems but do not describe the principles behind the solution and the process by which the specific solution was arrived at. The approach examined in this paper can be viewed as asking how would Nature solve this specific problem not how did Nature solve a similar problem. Thus this work does not fit into the two previously discussed groups of methods.

There currently is a great deal of research occurring in bio-inspired design based on the idea of abstraction. When engineers use nature as inspiration for designs, one of the major problems encountered is that biological processes and concepts cannot be easily applied to engineering design [18]. Research into abstraction to enable bio-inspired design focuses on converting functions and characteristics of biological analogs into concepts that can directly be applied to engineering problems. The advantage of this approach is that it allows engineers to perform Bio-inspired Design without having a background in biology or the need to perform significant research and analysis on potential analogs. This saves time in the design process allowing for faster design iteration time. An example of this process is the SAPPhIRE model [18]. This model describes seven layers of abstraction that can be generated to connect Biology to Engineering. Presently, research is going to on to fully explore each level of this model [18]. Further work has

been done in the area of converting problems between the domains of engineering and biology. This involves decomposing the problem into an abstract representation that can be used to transfer the analog or design problem into the others domain [19]. These works are primarily done with the intent of converting the design problem into the biological domain via the abstraction. Abstraction takes the functions of a specific analog and converts them to a form that can be more easily applied to engineering problems. As mentioned previously, the strategies considered in this paper not only deal with the functions but the intent behind those functions. The approach in this paper focuses on what is being accomplished by the biological analogs instead of the analog's characteristics. This allows for seemingly unrelated analogs to be proposed as potential inspiration and gives the designer insight into how their specific design problem could be solved in nature. Instead of asking how a similar problem was solved in nature this paper explores the question of how would a specific problem is solved in nature.

Fault Adaptive Design

The current direction of research in to fault adaption and robust design in general is in the area of programming and digital adaptation. An example of recent research in this area is the development of a trial and error computer program for an 8 legged robot model [20]. These approaches do not use hardware modification instead relying on the programming of a mechanism to adapt to a fault. Designs like this are also not 100% permanent, often simply providing a stop gap until repairs can be made. Biologically Inspired Design can bring a new approach to this area by dealing with hardware modification, chemical processes and even

analyzing how living organisms adapt mentally to faults in their bodies. This research specifically seeks provide a tool to help bring inspiration from nature into this field of research.

Reconfigurable and flexible systems change over the course of the systems life to account for changes in the system itself or in external factors [1]. Work in this area is not directly tied to Biologically Inspired Design but is a key area of interest for future design work. The advantage of applying BID to this area is that many examples of similar techniques in nature show some very useful characteristics. For example, it is logical to assume that the predatory nature of many organisms causes other organisms to need to rapidly adapt in order to survive. This then leads to the idea that many of the examples we can find in nature adapt rapidly to changing conditions which is a very useful characteristic in complex systems.

From this short summary, it can be seen that Fault Adaptive Design exists as a critical topic in system design and that much of this work is in the area of programming and configuration modification. Biology shows great promise as an area for integration in this field because of some of the inherit strength of natural systems.

Strategy and Planning

The most relevant example of developing strategies and tactics in hostile environments comes from military theory [21]. There is substantial literature available about the military operation performed in that field. This area also has placed significant effort in developing the operation and making it as abstract as possible. One of the principle texts in military theory is Sun Tzu's "The Art of War" [22]. In "the Art of War" the author addresses the case of a military commander leading a nation's military forces in a conflict. During this discussion the author

describes two different aspects to the execution of the campaign; these two concepts are *strategy* and *tactics.*

In a military structure, strategy and tactics do not have concrete definitions but rather the two terms can be used to describe the same thing but have different perspective. This arises from the use of an organized command structure of a military where a commanding general has strategy and tactics and then passes on orders to their subordinates who then treat the commander's orders as their strategy.

In Frederick the Great's Instructions to His Generals the whole text is built as instructions given to subordinates [23]. Frederick the Great also specifies strategy and tactics in his work, although indirectly. In the chapter on troop dispositions, the author describes the method of deploying forces on a battlefield. The overarching strategy of these deployments is to ensure his army is deployed in the spot most advantageous to that particular type of troop. He has the strategy of optimizing his army's ability based on terrain and describes several situations and how to deploy forces in each situation. Ideas such as this prove that an optimized strategy can be very effective in the specific execution of a task and can be applied to different situations without modification.

In the business field a similar approach can also be seen. Harvard Business Review investigated the definition of strategy from various sources and concluded with a definition from a business perspective [24]. This can be summarized as how individuals within an organization make decisions and determine how to accomplish objectives. This definition shares several traits with the definition presented in military theory. The most important similarity however is the emphasis on the method behind solving a problem instead of how to solve the problem. It removes the specific case from the discussion and deals only with the intent and plans behind it.

THEOERETICAL FRAMEWORK

This work leverages the concepts of strategies and biologically inspired design to develop a novel approach for bio-inspired fault adaptive design. To do this we develop a generalized framework for utilizing strategy in engineering design.

A Model of Engineering Design Theory

One way of abstracting the engineering design process is as the application of information for the purpose of solving a problem. For example, engineers are presented with a problem, collect relevant information about the problem and use that information to develop a solution to the problem. Consider C-K theory, which defines both knowledge and concepts as central elements to the design process. These are analogous to information and application aspects of design [25]. In Systematic Design [26], designers move from the abstract space into specific solutions while in Axiomatic Design [27], there are information and independence axioms which find specific applications. Logically, based off of this representation, engineering design research can be shown to either have the goal of expanding information available to engineers or in improving the application process (search and syntheses respectively).
Using the previous discussion, the way in which engineers solve problems can be modeled as a series of decisions that begin with stating the problem followed by preforming the engineering process and arriving at a solution. The engineering process that is preformed will be referred to as an operation so the design theory can be summarized as problem statement, operation, and solution preformed in series. Within the application section is the iterative process by which engineers refine ideas into specific solutions. The operation can be further subdivided into

information and application, which occur in series with each other. The diagram below shows a visual representation of this idea.

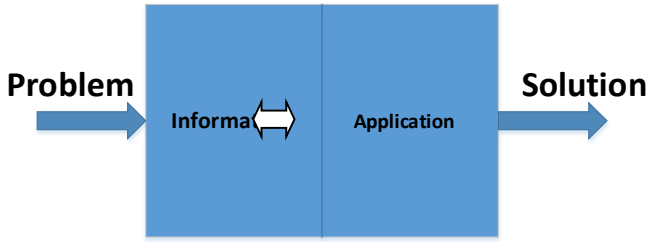

Fig. 1 Diagram of the traditional design process

Strategy and Tactics Perspective

Military commanders are presented with a problem that demands a solution and perform the operation of military theory on the problem to determine that solution. The operation of military theory is the development plans of the commander for a specific engagement. The operation preformed begins with collecting information relating to the problem. In this case, information is the current situation, information about past situations and restrictions or constraints. Then this information is applied to the problem to determine a specific solution that satisfies the constraints. The commander can further add constraints (which are part of the information) to change the solution to the fastest or cheapest route possible.

Applying these concepts to engineering design, we define the following:

- **Strategy:** The plan or method for achieving a goal. The goal is the solution to the problem posed during the design process.
- **Tactics:** The mechanism by which the goal is achieved. In simpler terms, strategy is what the design is trying to do, and tactics is how the designer goes about doing it.

These terms fit onto the model presented previously as a pair of parallel processes that overlap the information and application in the operation of the model. Both strategy and tactics require information to be collected an applied but both occur in parallel in the model. If Figure 1 is revisited with strategy and tactics overlaid in would appear as seen in Figure 2.

Fig. 2 Overlaying the traditional model of design with the concept of strategy and tactics

From this perspective, the engineering operation consists of two parallel processes that are strategy and tactics. Strategy relates to the intent of the design or direction of the design while tactics are the exact details about how the strategy is going to be executed. It should be noted that in the case of a design group hierarchy, that the design lead determines the strategy and tactics for the design and then assigns subordinate designers to execute specific things which are the design group leader's tactics. The subordinate designers are then given a task which becomes their strategy. This hierarchy shows that a specific design decision can be both a strategy and a tactic depending on where in the hierarchy it is being considered.

Strategies are the plan by which a solution is achieved. It includes any principles, equations, problem specific methods or tools and the overall plan by which those are selected and applied.

Consider a simple fluid flow design problem. For example, finding the exit velocity of a laminar flow in a tube with known inlet and exit pressure and inlet velocity. To solve this, simply apply the conservation of momentum to calculate the exit velocity. In this example, the principle of the conservation of momentum and the equations forms the strategy. The tactics are the specific application of the equations to the problem and the sequence the equations are applied.
In summary, the focus of this tool is on searching strategies, which are combinations of principles, the execution of those principles and the concepts by which they were selected. Traditional analog based approaches search based off of traits, behaviors and characteristics of the analogs which may or may not be modified into a more appropriate form for designers.

STRATEGY MAPPING TOOL

Based on this framework of strategies and tactics overlaid on the design process, we identified specific strategies found in nature and developed a tool to aid designers in searching those strategies. The goal of this tool is to provide the designer with both the tactics nature used and the strategy behind a database of fault adaptive examples in the natural world. Over 150 examples of fault adaptation in nature were identified. The examples included were collected from a literature search in the field of biology and are not necessarily all relevant examples. The analogs are the tactics in this situation and the principles behind them are the strategies. The tool takes a similar form to a flow chart, with the designer beginning at an initial location on the tool. The tool then presents the designer with a group of paths that lead to examples with fundamentally different strategies. The designer begins a path that starts with a binary question. The answer to this binary question indicates where to proceed next along the path. This then

begins a series of similar tasks where at each point the designer is presented with binary question and the designer must answer the question. That answer will advance the designer to the next point indicated. This continues until the designer reaches the conclusion of the path and is presented with biological examples that satisfy the same questions in the same way. The questions and their answers each form a component of the strategy for that set of analogs. These examples are usable as analogs for further design work and are the tactics by which nature solved the problem. The questions and their answers are the strategy by which nature's solution was derived. The strength of this concept is that it shows how nature solved the problem (tactics) and what nature was trying to do, including some constraints (strategy). A diagram showing the design of the tool is seen in Figure 3.

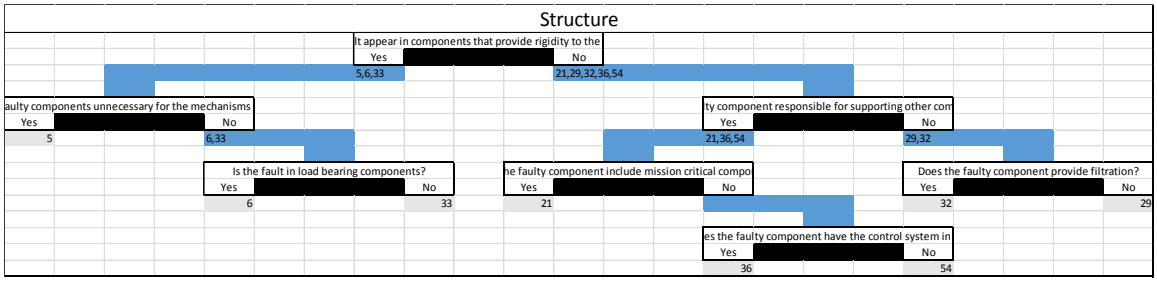

Fig. 3 Diagram of the strategy mapping tool

Designers will be able to see other potential possibilities which allow them to easily change past answers or predict if the current path has any value. The intent of the tool is that designers can see where the tool will take them and that means that designers need access to the whole tool at one time. The fault adaption examples are in an appendix to the tool and numbered in a way consistent with the path numbering for ease of access. An example of a tactic analog candidate is shown in Figure 4.

The design tool has 4 primary branches, replace, repair, repurpose and readjust. These correspond to different end goals of the various strategies seen in nature.

1. Replace: An adaption where a faulty component is completely or partially replaced by a new one.
2. Repair: An adaptation where a faulty component is brought back to full functionality.
3. Repurpose: Adaptations which use other components and characteristics of the faulty system to mimic the function of the faulty component in that system.
4. Readjust: Adaptations which adjust the programming or behavior of the system to work around the fault without fixing it.

Within each of these branches are binary yes/no questions that are answered with respect to the system being designed. Example questions include “Does the adaptation need to occur before deployment?” and “Is nonoperational time usable?”. The first question is answered yes if the adaptation to remove/accommodate the fault needs to occur before the faulty component is deployed within the system. The designer would then follow the path indicated by that particular answer which will lead to a new binary

34: Mexican axolotl, ambystoma mexicanum
The Mexican Axolotl is a salamander in the amphibian class. It can live 10 to 15 years in the wild but are considered endangered due to the water pollution, trading business, and being a food delicacy in Mexico. The axolotl has a great ability of regenerating its limbs and spinal cord as true limbs, muscles, and differentiated cells, not as scar tissues.
After the limb is amputated a plasma clot forms and the epidermal cells from the stump migrate to cover the wound surface and form the obligatory wound epidermis. This layer continues to reproduce and forms the apical ectodermal cap. The cells under the apical ectodermal cap undergo dedifferentiation and genes that express differentiated tissues, such as mrf4 and myf5, are down-regulated and msxi, proliferating progress zone, is up-regulated. The undifferentiated cells beneath the apical ectodermal cap are called the regeneration blastema. These cells will multiply and differentiate into the structures of the limb by pax7+ cells (scifinder), which are regulated by tgf-beta1. Down-regulation of p53 is essential to form the blastema, and later on in the healing process up-regulation is needed for re-differentiation of the cells. A major difference Godwin (25) found in axolotl regrowth compared to mammalian healing is that the presence of macrophages and pro-inflammatory and anti-inflammatory cytokine signals in the blastema within hours of the amputation are required to stimulate and sustain regeneration (pnas). This allows for no tissue scarring and perfect regrowth of the limb.

See references (28-

Fig. 4 Example of a biological analog

question and eventually a group of biological analogs that all satisfy that particular answer to that question. The component of the strategy this question generates is that a suitable design for this fault would need to address the fault prior to the components deployment if this was a problem in nature.

The process by which a designer comes to this analog is as follows. The designer begins at Tier 1 and is posed with a binary question with each of the two possible answers having an indicated path to take if that answer is chosen. This leads to a new binary question until the end is reached on Tier 1. The final result of the pathway on Tier 1 will tell the designer where in Tier 2 to begin. This leads to another result which indicates where to proceed on Tier 3. Tier 3 results are either numerical reference numbers for a group of one or more analogs or a Tier 4 starting point. Tier 4 results in a group of one or more analogs for use. The analog(s) provided can be used as biological analogs but they all share the same strategy. The strategy is based off of the answers to the binary questions. Each binary question and its corresponding answer is a component of the strategy for all analogs that are reached from that path. The strategy for the entire problem is the combination of these components. Thus a designer is left with one ore more analogs, which are tactics, and the strategy that they are all built on.

ILLUSTRATIVE CASE STUDY

To illustrate this approach and the tool developed we present a conceptual model of the design of exhaust system of a consumer car that can adapt to damage to the pipes by replacing the faulty component. This begins in the Replace section at Tier 1. The first question is does the faulty component directly affect the ability for the system to complete its mission? A damaged pipe does not directly affect the mission of a car to transport people or cargo so the answer is no. The next question is whether the fault is in the system's outer structure which it is not so the "no" path is followed. The final question is whether the faulty component is part of the fuel system. The exhaust is responsible for removing the byproducts of the fuel system so the answer is yes.

With this result the tool yields the result of 7 which is the Fuel System on the table for Tier 1. This means go to the fuel system chart on the Replace Tier 2. It is worth noting at this point that the Tier 1 questions narrow down the system because it was found that solutions in the natural world have similar strategies for similar system characteristics. Following this through to Tier 3 yields the following strategy characteristics.

1. The faulty component does not directly affect the ability of the system to complete its mission
2. The faulty component is not part of the outer structure
3. The fault is in the fuel system
4. The fault is in the components responsible for removing fuel byproducts
5. Removal of the damaged section cannot be achieved
6. Material assignment must occur before deployment
7. Existing material can be used
8. Nonoperational time can be used

This forms the basis of the strategy that is satisfied by the analog number 29 in the Replace analogs which is the rat and its ability to regenerate its liver after partial removal.

From this several design concepts can be generated. The first is a modular piping system which would change the flow rate of exhaust through other pipes to account for this fault. It still allows for the use of the damaged section and exactly how the changes are made is open because the times when the system is not in use are viable. A second design that could be utilized is a deployable gap filler to address cracks and replace the missing material. This would utilize the

damaged sections as the basis for the replacement of the damaged areas of the pipes. These designs can then utilize the example of the rat liver as inspiration for the implementation in the specific case of the vehicle exhaust. If the designer decides that nonoperational time cannot be used a different response would be chosen which yields different analogs and potentially different solutions.

A complete list is provided in the Appendix of all the questions contained in the tool. The questions are all identified with a binary callout that, starting from left to right, which identifies the answers to the previous questions that need to be chosen to come to that question. A "1" is used for yes and a "0" is used for no. Each binary callout is used multiple times, one for each of repair, replace, repurpose and reprogram and all the callouts begin with the digit 1.

DISCUSSION

The primary advantage of this tool is the recognition of the strategy and tactics of the solution. This allows designers to use either the strategy or the tactic as a biological analog for the design process. This information is not provided in any other bio-inspired design tool. This also has the effect of allowing the designer to use just the strategy of the analog. This is useful because nature does not have a wheel so to speak. If the designer requires a bio-inspired fault adaptive solution for a vehicle wheel normally the designer would not be able to find one. However, this tool allows the designer to determine how nature would have solved that problem even though no analog exists. The second major advantage of this tool is its flexibility in allowing designers to make easy changes. If a change needs to be made the designer can easily

see the potential consequences of that change and make that change by simply going to a different page.

The primary advantage of this approach is that it does not require a biological analog to already be selected. It is usable only with a basic understanding of the system being designed. Given that this tool does not require an analog it can be viewed as a search tool for biological analogs. This is a suitable purpose for it but it also offers a view of the strategy behind the analog which is similar to the abstraction concepts achieved through an abstraction method. Thus this tool offers the designer both a search aid and a design aid.

This approach is similar to Biocards [13] but differs in its emphasis on the strategy instead of the analog (tactics). Comparisons can also be drawn between this work and BioTriz but the key difference is that BioTriz [14] concentrates on principles whereas the strategies presented in this work not only include principles but their use in solving the problem as well. Finally some parallels can be drawn to c-k theory and this work is similar in many ways. The final products are very similar in that what c-k theory creates can be considered a strategy but the difference is that c-k theory develops only one strategy while this work shows many different strategies. The designer is also allowed to change the problem definition during the process in this work. Finally c-k theory develops a new strategy whereas this tool searches strategies seen in nature within a small domain (fault adaption).

Like other Biologically Inspired Design tools this tool is limited only to the analogs it currently contains. Further expansion of the tool is possible but if the domain of fault adaption is not relevant to the designer's work then the tool has limited usage. Sun Tzu states that an infinite number of strategies and tactics exist within military theory, given that this tool is derived from military theory it is not unreasonable to assume that it also implies that an infinite number of

strategies exist within nature. Nature continuously changes its designs via evolution and the environment that those designs are placed in constantly changes. However, there may only be a finite amount of mass in the universe and therefore a finite number of combinations that can be observed. This could lead to only a limited number of strategies being employed by nature. The second major limitation is the tool does not guide the designer through the use of the information it provides. The tool simply provides the information about nature's tactics and strategy with no indication as to how to apply it to the design problem being considered. These limitations are deemed acceptable because strategy is abstract. Even if the analog the tool provides is not relevant in any way, the strategy is suitably general that it can be applied to the vast majority of situations. The second limitation is deemed acceptable because the goal of the tool is to provide a general strategy with a specific example. The strategy will be presented in a simple way that is not depended on context thus allowing the strategy to be easily dissected and applied.

CONCLUSIONS

A new design tool was developed for bio-inspired fault adaptive systems that illustrates the ideas of strategy and tactics from an engineering perspective. The tool provides designers with both the strategy and tactics of nature's solution to a similar problem. This tool is designed be used at any stage of the design process and allows for easy changing of the system being designed. The limitations are primarily its limited scope and lack of assistance after determining a suitable biological analog. The tool's most significant offering is that it combines both a search tool and offers a potential framework for implementation of that analog into a mechanical system. Further work to be done with this project involves testing the design tool and performing

changes as they are deemed necessary. This testing will also include a simple survey about the effectiveness of the tool from the perspective of student designers. Another area of further study may be in the area of strategy optimization. During the creation of this tool it was noticed that several different strategies could yield the same tactics for the same problem and research into methods to determine which is best would be useful in optimizing the tool for use. The identification and implementation of natural strategies is a potentially useful approach in fault adaptive design. This work contributes to this effort by providing both a design framework and a deep library of analogs.

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FIGURE CAPTION LIST

Fig. 1 Diagram of the traditional design process

APPENDIX

	Repair Tier 1
1	Are any factors that are external to the mechanism, usable?
11	Are any of those factors manufactured?
10	Is there a trigger event to begin the repair?
111	Do those factors directly replace the damaged component?
110	Is the faulty component used directly?
101	Is there any foreign material preventing a return to full functionality?
1011	Is the foreign material removable?
1010	Does the healing change the characteristics of the system?
10100	Can the foreign material be destroyed?
10110	Can the foreign material be destroyed?
1111	Does the factor come from the original mechanism?
11111	Is the component already assembled?
11110	Is the factor produced in the same way as the mechanism?
111100	Is the component from the same type of mechanism?
1111001	Is the component assembled before the fault occurred?
	Repurpose Tier 1
1	Is external assistance used?
11	Is the intent to mimic the lost part directly?
10	Can the mechanism maintain the same role in the system?
1101	Does the adaptation cover up possibly good components?
110	Is there control over the repurposed components?
1011	Is the material eventually removed by normal processes?

101	Is there a foreign material in the system?
100	Can the mechanism include both original and new role at time of deployment?
	Readjust Tier 1
1	Can an aspect of the environment or mechanism change to allow for return to full functionality?
11	Can a new behavior be used to return to full functionality?
10	Are physical changes possible to the mechanism?
111	Can the behavior be accomplished without external assistance?
101	Can the control system be used to rectify problem?
100	Is the fault due to changes in the environment?
1001	Can other parts be used to minimize the effects of the fault?
10011	Is the fault due to changes in the environment?
100111	Can the operational environment be changed to adapt to the fault?
1001110	Can the undesirable environmental effects be removed by changing the coating?
	Replace Tier 1
1	Is the fault in the components that allow the mechanism to perform its mission?
11	Is the fault in components that move?
10	Is the faulty component part of the mechanism's body?
111	Is the fault in components that make the mechanism move?
110	Is the fault in the mechanisms controls?

101	Is the faulty component in the structure of the mechanism?
100	Is the faulty component in the fuel system?
	Replace Tier 2
1000	Is the damaged component necessary for full functionality?
10001	Is the damaged component comprised of multiple parts?
10000	Is the damaged component necessary for waste removal?
1110	Is the damaged component needed to deploy the additional?
11100	Is the original system going to continue to exist?
1010	Does the damaged component provide protection?
10101	Is the component serve any other purpose than protection?
1001	Is the fault in the fuel filtration system?
10011	Is the fault in the fuel filtration components?
10010	Is the fault in the components responsible for transporting the fuel?
100111	Is the fault in the components responsible for removing fuel consumption byproducts?
100110	Is the fault in fuel storage?
100100	Is the fault in fuel pump or similar component?
1101	Is the fault in the components responsible for sending signals?
11011	Is the fault only limited to non sensory components?
11010	Is the fault in components responsible for relaying sensor data?
110111	Is the fault in the components responsible for transporting signals?
110110	Does the fault affect all components responsible for relaying sensory data?
110100	Is the fault in the optical sensors?

1011	Does the fault appear in components that provide rigidity to the mechanism?
10111	Are the faulty components unnecessary for the mechanisms mission?
10110	Is the faulty component responsible for supporting other components?
101110	Is the fault in load bearing components?
101101	Does the faulty component include mission critical components?
101100	Does the faulty component provide filtration?
1011010	Does the faulty component have the control system in it?
1011100	Do multiple versions of the components exist for the faulty component?
1111	Is the faulty component a part of a larger mechanism designed to move?
11111	Is the faulty component a joint?
11110	Is the component designed to move objects, including the mechanism?
111111	Is the fault component responsible for moving the mechanism around?
111110	Is the fault component not needed for stability?
111101	Is the fault component not needed for stability?
1111101	Is the faulty component responsible for manipulating objects?
1111011	Does the component manipulate other objects?
1100	Does the faulty component responsible for visual data acquisition?
11001	Is the faulty component only a part of the optics system?
11000	Is the faulty component used for sensing the location of objects?
110011	Is the faulty component at least partly responsible for data acquisition?
110001	Is the faulty component not rigid?
110000	Is the faulty component not responsible for sound reception?

1100111	Does the faulty component directly collect visual data?
1100110	Does the faulty component focus the sensory data?
1100011	Does the mechanism control the component?
1100010	Is the faulty component used for protection?
1100001	Does the faulty component check compatibility as part of its function?
	Replace Tier 3
1111010	Is the damaged structure removed?
1101101	Are multiple sites available for material?
1100000	Is the functionality completely compromised?
111100	Is the damage before deployment?
1001001	Are multiple control mechanisms used?
11111010	Are structural components present in component?
100011	Are any damaged components present?
1111101	Is the damaged structure removed?
101101010	Are multiple materials available?
10110101	Does the adaptation occur simultaneously?
10111001	Does a specific component need to be replaced?
101110011	Can the part be assembled on site?
11111011	Is the part always supposed to be present?
111110111	Does the part need to change dimensions?
11001101	Is the component still attached?
110011011	Is the component only partially damaged?
10110100	Is the system completely destroyed?

101101000	Is any material from the previous system present?
101011	Is the part completely removed?
1010111	Is the damaged area protected?
1010100	Can the environment be used to affect the adaptation process?
101010	Is the adaptation continuous?
1010101	Is the adaptation targeted?
10100	Is the surrounding structure damaged?
101000	Is the adaptation internal?
1101111	Does the adaptation need to occur before deployment?
11011111	Is the damaged area on both sides of the fault?
11011110	Is the damaged area not removed?
1001110	Is removal of the damaged section possible?
100111001	Does differentiation occur before attachment?
100111000	Can the existing material be used?
10011100	Is nonoperational time usable?
1001111	Is there a preprepared package of material ready for the adaptation?
10011110	Is any debris cleared from the damaged area?
10111000	Are signals generated coincidentally to the adaptation?
101110001	Can the mechanism continue function until the component is replaced?
1011100010	Do debris need to be cleared from the damaged area?
11110111	Does the adaptation occur in stages?
111101111	Is the replaced component compartmentalized?
1111011110	Are the controls fixed first?

11110110	Is there a point on the mechanism, that the damage occurred at, that was designed to be the point of failure?
111101101	Does the adaptation continue after assembly?
111101100	Does the adaptation occur simultaneously?
1111011010	Is the assembly simultaneous?

Experimental Exploration of a Biologically Inspired Design Tool for Fault Adaption

Abstract

In this paper we present an approach to validate a novel design tool for Bio-Inspired Fault Adaption that uses a method called Strategy Mapping. The goal of the design tool is to assist designers trying to develop fault adaptive behaviors in engineering systems using nature as inspiration. The natural world is filled with examples of fault adaptive behaviors but engineers have struggled to integrate those examples into designs due to the different mechanisms and techniques used in those natural examples. In an effort to address this problem, the evaluated design tool looks to provide the strategy behind a specific set of analogs. This strategy describes the principles, concepts and decision making trends that, when applied to a specific problem, lead to a specific solution. To do this, the tool is comprised a series of binary questions that lead designers from the initial problem that they are attempting to satisfy, to a group of biological analogs and the accompanying strategy that those analogs satisfy. From this, it is believed that designers will have an easier time generating concepts that ultimately lead to a design that satisfies the problem to be solved. The tool was tested using several groups of engineering students addressing the same design problem and a metric was used to determine how effective the design tool and several others Biologically Inspired Design tools performed in comparison to each other. The groups rated the speed at which they generated concepts, the ease of generating those concepts, the value of the design tool and the difficulty in integrating their analogs into concepts. It was found that groups that used the Strategy Mapping Tool were better able to generate concepts, did so quicker and had an easier time integrating their analogs into designs than groups that used other Biologically Inspired Design Tools. With these results, several changes and further research directions are also provided.

INTRODUCTION

For most engineered systems a certain amount of robustness is required. Usually, components are designed with safety factors and systems are evaluated under risk analysis procedures. When a system is more complex, there are more potential ways it can fail and failure would mean the system needs more regular maintenance or possibly even replacement. By utilizing fault adaptive behaviors, engineers can design systems that are overall more robust and can continue to function even though some aspect of the system has failed. This would in turn allow systems to continue to function until the next scheduled maintenance or until the system can be replaced. A similar set of behaviors can be seen in nature so it is logical for engineers to look these natural behaviors as inspiration for future designs. The natural world consists of organisms in a constant battle for survival which implies that organisms need to be optimized to survive. If a fault occurs in a natural system (organism), that system must adapt quickly in order to survive and must do so as efficiently as possible. Both of these trends are desirable to engineers, which makes using nature as an analog for engineering design even more attractive. There is however a problem with integrating natural examples of fault adaption into engineering and that problem is that very different mechanisms, techniques and processes are used by nature. Engineers do not have access to the same tools used in nature and this creates a challenge in utilizing natural analogs for engineering design. In response to this challenge, a design tool was developed that attempts to assist in using nature as an analog by using *strategies* instead of specific analog characteristics. In this work we validate this tool from a design usefulness perspective.

Specifically, this paper discusses implementing a design tool based on identifying fault adaption strategies and providing these as well as the example organism as design analogs for the

engineer. This is compared with using a directed analog search method with the online web interface of AskNature [1] and undirected search method as a control group. This experiment was evaluated with groups of students in undergraduate courses using a consistent design prompt. Both the student's responses to the activity as well as an evaluation of the designs produced are discussed and indicate that, for implementing adaption in design, the evaluated design tool can be a powerful aid. The supporting research for for this experimental study is presented next.

BACKGROUND

AskNature and Biologically Inspired Design

Biologically Inspired Design is a design by analogy technique that uses nature as an analog for designs in engineering. Research into this area of design primarily focuses on either matching an analog with a design problem or converting the analog into a form that is much more readily applied to a design problem. One of the most common tools used is AskNature [1] which is an online database that uses function as a basis for selecting biological analogs. The premise is that if a designer needs inspirations for a mechanism to perform a specific function then AskNature will help in locating suitable analogs that perform that function in nature. This method was selected as a comparison method for this experiment because of similarities with the Strategy Mapping Tool. First, both AskNature and the Strategy Mapping Tool provide a set of analogs after the user inputs information relating to the system being designed. One key difference is that the information provided to the Strategy Mapping Tool is responses to guided questions and the responses form the basis for the strategy which is what the tool aims to

provide. AskNature uses its inputs as known quantities to provide analogs to the user. The second major point of similarity is AskNature's use of function as the search parameter while strategy mapping uses the strategy. This comes from the way strategy is defined as what is trying to be accomplished. This can easily be taken as the function of the mechanism in a very simple sense. However a strategy is more than function, it is how that function is going to be achieved. It is the collection of principles, decision making trends and goals that are applied to a problem as the basis for a solution. These two similarities are the reason why AskNature was selected for comparison to strategy mapping. The two methods appear to be very similar and use similar mechanisms but both provided very different results to the user.

There are other methods used for enabling Biologically Inspired Design. One such method is simply using biological analog as a direct model for a mechanism in a method called biomimicry. An example of implementing biomimicry is DynaRoACH developed by the University of California-Berkely [2] which uses the analog of an American Cockroach and mimics its gait directly to develop a robot. Another method involves converting analogs into a more usable form that can be more easily applied to engineering problems. For example, Nagel et al develop a computational approach to help integrate analogs into designs at an early stage [3]. The goal of this research is to allow engineers, who have minimal knowledge of biology, to easily identify relevant analogs to their design problem at a nearly stage. There are many more examples of methods, most of which involve converting an analog into a more useable form, thus allowing less directly applicable analogs to be utilized.

Experimentation and Verification of BID Tools

Validation of Biologically Inspired Design Tools is still an area of ongoing research. Validation is an important aspect of Biologically Inspired Design because, as with any field of research, it is necessary to know if the approach being used is consistent with expectations. Versos et al [4] performed an exhaustive analysis of the various techniques used to validate Biologically Inspired Design. One of the major areas of interest was comparative analysis. Versos et al analyze various methods in Bio-Inspired Design and attempts to identify where each one succeeds and fails with respect to the other. From this, a set of procedures are proposed to be included in Bio-Inspired Design validations. Some examples include from optimization and multiple requirements satisfaction. These are proposed by the authors as several areas of analysis for validation but are not explored in detail. This area has been explored by other authors [5] but not in the same exhaustive manner.

Validation of a design tool by novice (student) users is limited from the onset. However, research in Biologically Inspired Design Tools and methods have found that student-based experiments are very useful for indicating performance and refining the tools or method in question [9-12]. The experiment presented in this work serves a similar purpose in providing insight into the effectiveness of the tool and refining the next research objective. Developing a quantifiable metric to validate the Strategy Mapping Tool is challenging. The Strategy Mapping Tool hypothesizes that utilizing strategies instead of specific analogs is more beneficial than the methodology used by existing tools such as AskNature. This paper presents the results from the comparative experimental study to evaluate that hypothesis.

Strategy

The design tool used in the experiment performed in the paper uses the principles of strategy and tactics which is primarily drawn from military theory. Sir Rupert Smith's work, *The Utility of Force*, is a modern adaptation of Sun Tzu's *The Art of War* and primarily focuses on the macroscale operations and decisions a military commander may encounter [6]. In this work, strategy is introduced along with the companion concept of tactics. These two concepts can broadly be defined as what a general is trying to accomplish and how a general goes about doing so respectively. Sir Rupert Smith claims that strategies are timeless and context independent. The breakdown of strategy and tactics also appears in other major military works particularly Clausewitz's *On War* [7] and Robert Greene's *The 33 Strategies of War* [8]. Clauswitz illustrates the difference between the two very well by presupposing a specific strategy (national survival) and applying it to several different situations. By applying it to several different situations that one strategy yields multiple different tactics because how the strategy is accomplished must adapt to the problem. This leads to the idea that a strategy can be applied to different situations without any modification. The strategy will then lead to a set of tactics that are manifestations of the strategy with the specific situation. Robert Greene approaches the idea of strategy from another direction by applying many different strategies to the same problem thus illustrating that a problem can be approached with several different strategies, some of which yield the same tactics but for different reasons.

As seen in these works, a strategy can be applied to any situation and how that strategy is implemented is called the tactics and the tactics are specific to any given situation. If this same idea is applied to Bio-Inspired Design, then a biological analog is analogous to the tactics and there is currently no analog to strategy. The design tool tested in this paper is an attempt to develop strategies for a catalog of analogs (tactics) with the goal being to apply those strategies

to completely different situations than the analogs they were derived from. According to military theory this will allow for better solutions then simply attempting to match tactics up with design problems. The Strategy Mapping Tool that is being evaluated in this work implements this.

THE STRATEGY MAPPING TOOL

The Strategy Mapping tool uses the principles of strategy and tactics, as described in the previous section, as a framework for solving design problems using Biologically-Inspired Design. The premise is that all biological analogs are manifestations of a specific strategy when applied to a specific problem and that this manifestation is analogous to tactics as seen in military theory. Combined, the strategy and the tactics are a solution to the problem in question. Strategies are defined as what the designer is trying to do to solve the problem. For example, if a designer is presented with the problem of reducing the fuel consumption of an aircraft they may use the strategy of reducing the drag coefficient of the aircraft. Tactics are defined as how the designer goes about implementing the strategy. The tactics in the case of the aircraft fuel consumption example could be redesigning the fuselage or using a different airfoil depending on which is more applicable. Redesigning the fuselage or the airfoil are the tactics by which designer is implementing the strategy of reducing the drag of the aircraft.

The design tool was built with a collection of over 150 biological examples of fault adaption [13]. This collection was then organized by the strategies being implemented in each analog which yielded over 100 different strategies. These strategies were then put together in a tool which uses a series of binary questions to lead the designer through the strategies to the biological analogs. The binary questions are answered with respect to the problem the designer is

working on or the desired way of solving the problem if the designer already has an idea. The strategy presented by the tool is the strategy that would have been observed in nature to solve the specific problem the designer is working on based off of the analogs recorded. If the designer answered the binary questions based off of how they want the problem solved, it yields the strategy used in nature that is most consistent with that solution.

In order to ascertain how useful this tool is an experiment was conducted using engineering design students and the experiment and its results are discussed next.

EXPERIMENTAL SETUP

Objective and Hypothesis

One hypothesis of the Strategy Mapping Tool is that a designer will have an easier time generating concepts based on analogs from nature by using the strategy of the analog when compared to simply presenting analogs as with other Bio-Inspired Design tool. The second hypothesis, is that integrating those concepts will easier when strategy mapping is used. The comparison design tool is AskNature[1]. Both design tools provide the designer with a database of analogs, both seek to provide analogs instead of adapting an existing analog and both do so by searching for principles and characteristics present in the analog. Whether or not the Strategy Mapping tool meets the goal is determined by a simple metric that rates the tools on various categories such as iteration time and concept generation. The results are analyzed to determine how the Strategy Mapping tool and AskNature compare to each other. A control group using no Bio-Inspired Design tools is used as a comparison. From this experiment the effectiveness of the tool and any future changes were identified.

Experimental Groups

This experiment was performed by analyzing 11 groups performing similar tasks. The total number of students that participated in this experiment was 33. The eleven groups consisted of engineering students in a senior level undergraduate design course and senior level machine element design course. The students were all presented with the same design problem and constraints and asked to generate and submit as many concepts as possible, selecting one as a final concept. The students were required to use Bio-Inspired Design to address the design problem. Three groups were not provided a design tool (control groups) to assist in the design process, four were told to use AskNature[1], and the other four were provided the Strategy Mapping Tool.

The groups not using a design tool were instructed to search for an analog in any way they wished except for using any established design tool built for Bio-Inspired Design. For example, a simple Google search or personal experience was allowed. These groups were informed to turn in an article taken from an online encyclopedia relating to their analog with their final selected concept. The concepts not selected were not required to have an attached article. Groups that used AskNature were instructed to only use AskNature to search for their analogs. If the AskNature site did not provide adequate information to generate a concept then outside material was allowed, however AskNature had to be used to search for the analog. This set of groups was told to turn in their concepts and their final concept had to include a link to the relevant page on the AskNature website for later review. In addition, these groups were told to use AskNature's supporting documentation in order to figure out how to use the tool. The final set of groups were provided with the Strategy Mapping Tool and its supporting documentation

and were told that if they had any questions they were allowed to ask and receive help from the tool's designers. Groups using this method were expected to turn in the analog for their final concept in the form of the entry number in the tool's supporting documentation. As with the AskNature groups, outside sources were allowed to flesh out the analog but the Strategy Mapping Tool was the only acceptable search tool allowed.

Process

The engineering students were divided into 11 groups at the beginning of the semester for the class they participated in. Groups membership was based on the diversity of ethnicity of the students, and their schedule availability. These groups had prior design experience within the respective class. The groups were randomly assigned a method by which to incorporate biological principles into their designs. Three groups were not provided with any design tools to search for a biological analog or to assist in its incorporation. Four groups were then told to use AskNature[1] to search for their biological analogs and the final groups were given the Strategy Mapping Tool.

The design problem was to address the potential for a crack in the lens of a satellite telescope. The satellite was expected to exhibit fault adaptive behavior to address the crack. The groups were given one week to come up with a design to solve this problem. The students were asked to come up with several concepts and to present one of them as a solution. The final design was expected to be detailed enough that the mechanisms and biological principles are evident. It was not necessary for the design to be fully specified in terms of material and dimensions unless it is necessary to illustrate the principles in use. After the designs were collected, the students were provided with a questionnaire and the results were averaged out amongst the members of

the groups using the same technique. These results were then used as the basis of the conclusions reached for the experiment. The handout provided to the students is provided in Appendix 1.

Data Gathering Technique

Eleven groups were included in this experiment and each one was provided with the same set of questions upon completion of the experiment. Each individual member returned a filled out questionnaire with the group results. The response options for each question were presented to the students are on the Likert Scale with 5 points. The questionnaire is provided in Appendix 2.

The first question asked how easily the group was able to generate concepts. An aspect of one of the hypotheses of the Strategy Mapping Tool is that recognizing the strategy will allow for easier concept generation. With that in mind, the Strategy Mapping Tool should score better than AskNature or the control group. The second question was similar but relates to the speed of concept generation which again, according to the hypothesis, will be faster for the Strategy Mapping Tool. The last three questions were general usage questions. The third question was about Bio-Inspired Design in general and this question served to ascertain if a design tool was better than no design tool. An unstated assumption about the Strategy Mapping Tool is that having the tool is more beneficial than not having the tool. The fourth question is about the difficulty in integrating a concept into a design. The second hypothesis of the Strategy Mapping Tool is that strategies are easier to integrate than specific analog characterizes so as such it was expected that the Strategy Mapping Tool would score better in this area when compared to AskNature. The final question was about the usefulness of Bio-Inspired Design and was intended to provide an indication as to the value of the approach of Biologically Inspired Design in this

situation from the student's perspective. From this, it was expected that if the design tool really helped the design group, then Bio-Inspired Design would appear useful. If the group found the tool to be of little value then a lower score was expected. If one method or tool scores higher (except for question 1) than it represents a more positive results from the students. Question 1 was posed such that a lower score was more positive than a higher score. Finally, a total number of hours spent generating concepts was collected as was the number of concepts generated. The idea behind this is to see which method generated the most concepts per time.

RESULTS

Results of the Questions

A total of 32 questionnaires were collected and the numerical response to each question was cataloged and the results were put into a table. From that a graph of each question was created with the numerical answer plotted vs the number of responses with that answer. These are seen in Figures 1-5. Methods 1, 2 and 3 are using no tool, using AskNature, and the Strategy Mapping Tool respectively.

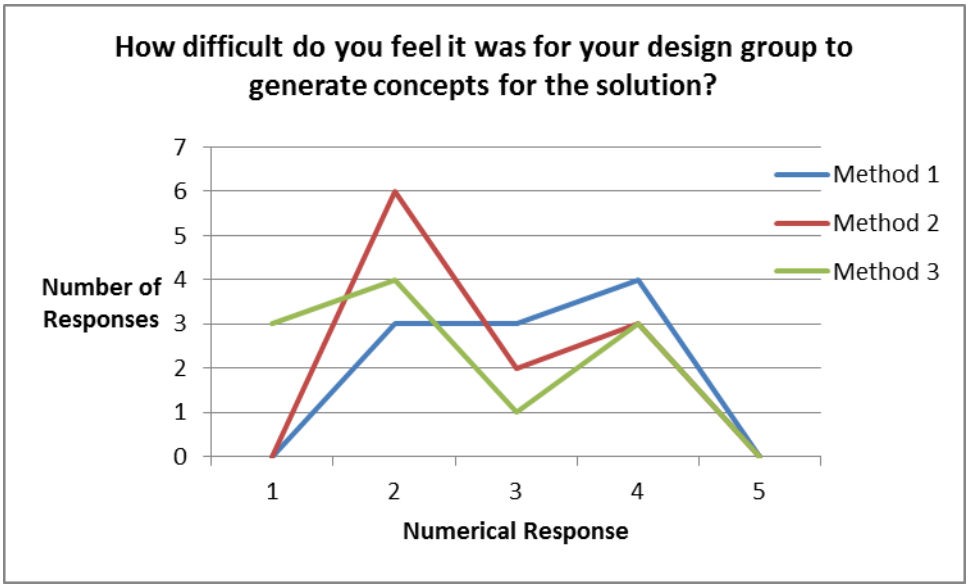

Figure 1: Results of Question 1

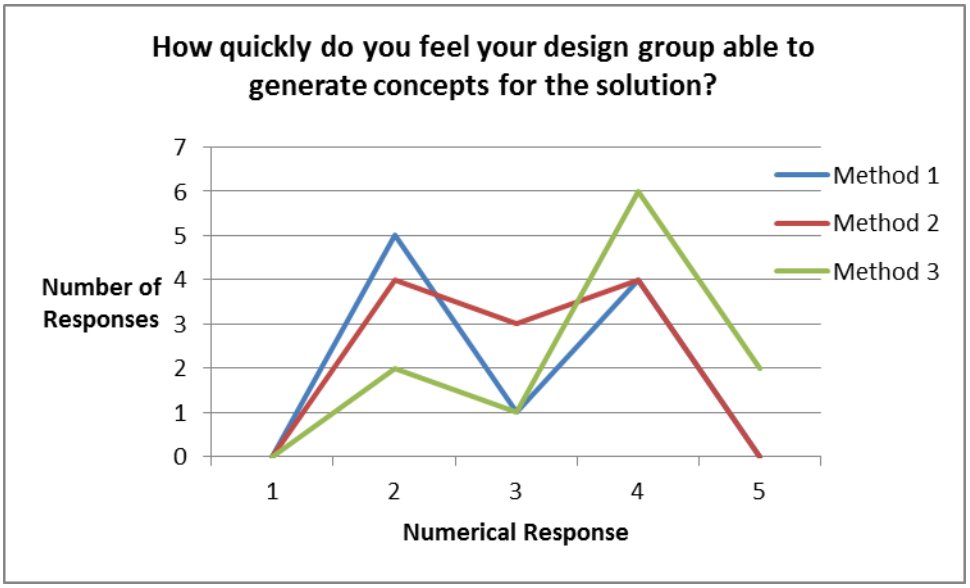

Figure 2: Results of Question 2

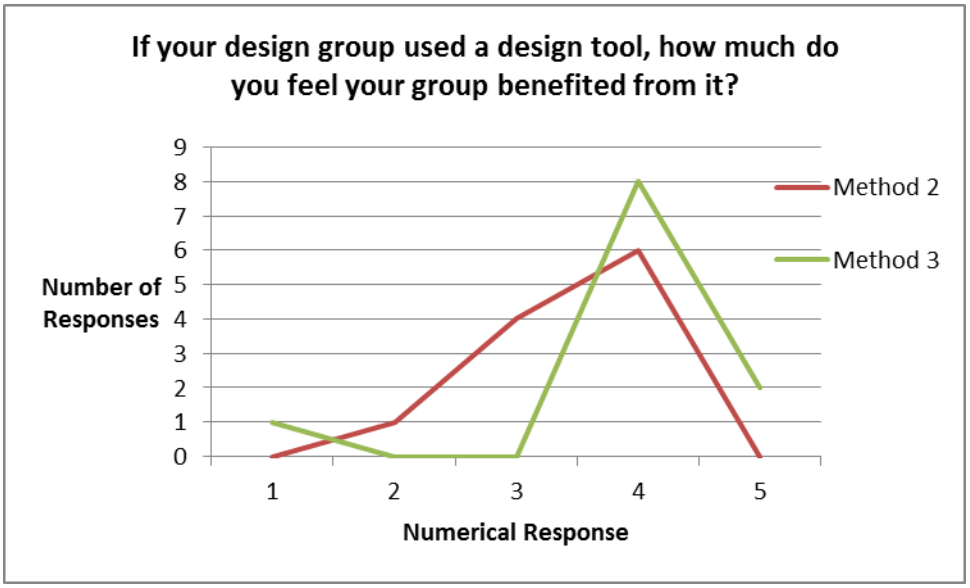

Figure 3: Results of Question 3

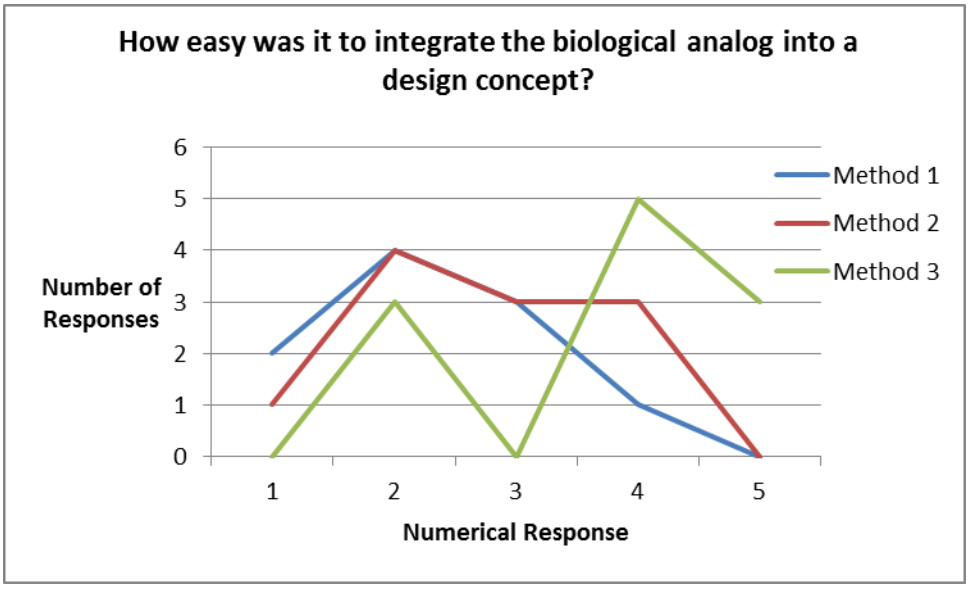

Figure 4: Results of Question 4

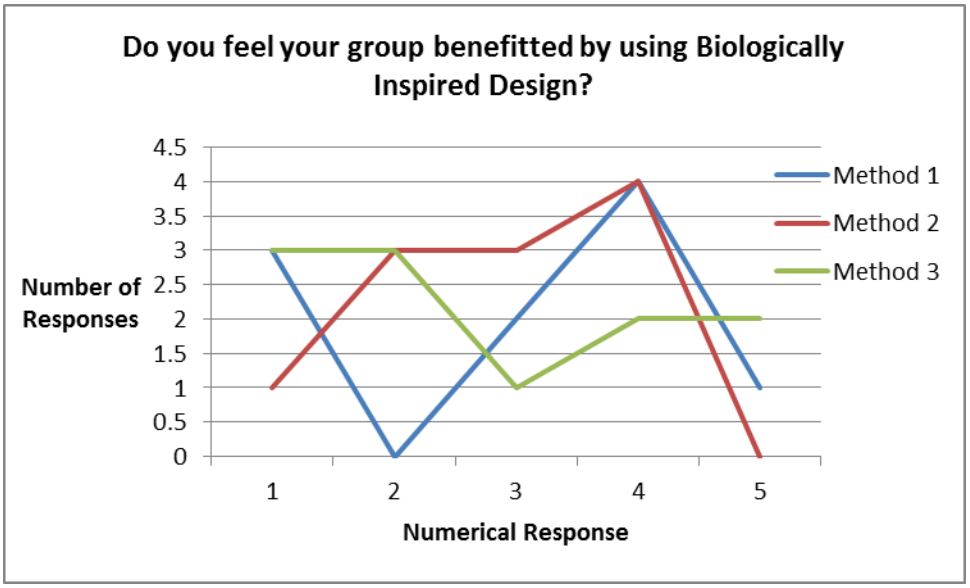

Figure 5: Results of Question 5

The number of concepts and number of hours spent working on the project are omitted from this table due to inconsistencies in the data. Group members reported different numbers and those did not match what was submitted. The results from the questions were then averaged and the average for each method was calculated. This resulting table can be seen in Table 1.

Table 1: Averaged Results from Questionnaire Responses

Method	**Ease of Concept Generation**	**Speed of Concept Generation**	**Was The Design Tool Used By The Group Useful**	**Integrating The Analog Was Easy**	**Group Benefitted From BID**
1	3.10	2.90	1.60	2.20	2.70
2	2.73	3.00	3.45	2.73	2.82
3	2.36	3.73	3.91	3.73	2.73

Due to the small sample size, a simple average was collected of each question response. From this we can see that Method 3, which uses the Strategy Mapping Tool was reported as easier to generate concepts, generated those concepts quicker and had a substantially easier time integrating their analogs when compared to Methods 1 and 2. Groups that used Method 2 however felt they benefitted more from the BID process but overall AskNature scored less than the Strategy Mapping Tool in other areas. Several students from the Method 1 reported results for question 3 when they did not use a design tool resulting in a value in Table 1 but it has no meaning because not every student responded and the question was unclear for their situation. Those that did respond likely assumed it was the search engine method and answered the question based off of that. All groups that used Methods 2 and 3 showed more positive results than those groups that did no use a design tool. From this table we can see the Strategy Mapping Tool outperformed AskNature in many categories and both AskNature and the Strategy Mapping Tool outperformed simple search engine method.

Results of the Concepts

The specific concepts generated by each group were also reviewed. Three group's concepts are presented here representing the three tested approaches. These groups were selected because they spent similar amounts of time and submitted the same number of concepts. It was also noted that these groups seemed to be representative of other groups using the same methods. All three groups submitted relatively detailed concepts and summaries of how the analogs they chose were used in the concepts.

The first set of concepts to be discussed were developed by a group using a generic internet search engine to find suitable analogs. This group will be referred to as Group A and its

concepts as 1, 2 and 3. This group submitted three concepts that used stem cells in the human eye, the ability of humans to heal from a cut and the regenerative process of a newt as analogs. Concept 1 was to provide the lens with a liquid repair mechanism that would harden to fill in a crack whenever a crack occurred. This concept was generated by using the idea that undifferentiated cells in the eye differentiate to fill in lost or damaged sections and that a liquid would mimic that effect in a mechanical system. Concept 2 was to use a similar method to concept 1 but enclose the lens in a case and pump the liquid in from outside the lens. This is based on the fact that the human body forms a scab and then cells are sent to the damaged area to repair it. Concept 3 used a newt as a model and that concept was very similar to the group's first concept. The key difference being that an active mechanism would be used to repair the lens instead of the passive mechanism used in the first concept. This group chose to their second concept as their final submission.

The second group used AskNature to locate analogs. This group also reported three concepts using Nurse Shark teeth, human skin and crocodile eye lenses as analogs. This group will be referred to as Group B its concepts as 1, 2 and 3. Concept 1 was to have multiple lenses on board the satellite in case of one cracking. The inspiration for this was based on how Nurse Sharks have multiple rows of teeth so that if one breaks there is another to replace it. Concept 2 uses human skin and involves lacing the lens with hollow fibers filled with a liquid. The liquid would be exposed to the low temperatures in orbit and when a crack occurs, it would freeze in the cracked area and fill it. This concept used human skin forming a scab as its analog. It should be noted that the Group A had a similar concept 2 but the difference is that Group B used the scab forming process as the analog whereas Group A used the formation of new tissue under the scab as their analog. Group B's concept 3 used the secondary lens on a crocodile as an analog to

create concept where a disposable, removable cover was used to prevent the fault from happening.

Group C used the Strategy Mapping Tool and also generated three concepts which will again be numbered 1, 2 and 3. This group used the Alaskan Wood Frog, American Shad and the Achatonoidea Snail as analogs. Concept 1 used the Alaskan Wood Frogs ability to shut off organs due to temperature fluctuations. The concept involves placing two clear plastic plates around the lens which is made of a polymer that has a low melting temperature. Between the plates and the lens will be liquid nitrogen with keeps the lens below its melting point. The plastic plates will then be polarized to generate an electric field through the lens and any cracks in the lens will disrupt the electric field. A voltmeter will register this change and pump the liquid nitrogen out of the cracked area causing the lens to melt in just that area and once the electric field returns to normal the liquid nitrogen will be pumped back in to refreeze the lens. Concept 2 uses the kidneys of the American Shad as an analog. The American Shad regulates the amount of salt in its body and can over time change between salt and fresh water. Using this as a model, Group C suggested a concept of a spring-mass damper system that would cause the lens to float allowing it to adjust to sudden shocks and vibrations that may occur during launch and transport. The group noted that the lens is mission critical so damage is not acceptable as is the case with the American Shad's salt level. The final concept, uses the Achationoida Snails ability to regenerate its shell if it cracks. It does this through a series of layers that combined, give the shell its properties and whenever a crack occurs the snail secretes a plasma corresponding to the damaged layers which repairs the crack. This was applied to the telescope by making the lens out of three layers (or more) and using a vibration sensor to determine if a crack occurred and how deep it was. This would then lead to the system releasing a gel, corresponding to the damaged

layer, which would then harden in the crack surface and fill it in. Each group's concept summaries are provided in Appendix 3. A visual representation of the groups and their analogs is provided in Table 2.

Table 2: Concept Summaries of Groups A, B and C

	Group A	Group B	Group C
Concept 1	Analog: Human Retinal Stem Cells	Analog: Nurse Shark Teeth	Analog: Alaskan Wood Frog
	Repair lens by freezing liquid contained in lens	Have redundant lenses	Use localized melting of lens to repair crack
Concept 2	Analog: Human Wound Healing	Analog: Human Wound Healing	Analog: American Shad
	Enclose lens and pump liquid in to fill gaps and then freeze liquid	Repair les by freezing liquid contained in nanotubes in lens	Spring-Mass damper to prevent crack
Concept 3	Analog: Newt Regenerative Process	Analog: Crocodile Eye Lens	Analog: Achatinoidea Snail
	Repair Lens with active repair system	Replaceable exterior cover	Layered lens with solidifying liquid

If these groups are compared, several interesting trends emerge. First is that Group C had far more developed concepts then the other two. This group went into great detail about specific mechanisms and techniques that would be used where the other groups provided less refined ideas. This also led to Group C's concepts being the most complicated.

The most common concept was refreezing liquids or gels to repair the crack and Group A's concepts were all related to this. Group B had two concepts (1 and 2) and so did Group 3 (1 and 3). However, Group C had a much more detailed and unique approach in both cases. Groups B and A used a crack to expose the gel/liquid to low temperatures while Group C used the crack to warm the gel and Group C used a layered approach instead of a single layer as seen in Groups A and B.

It also is an interesting trend in Group B, and in the AskNature groups in general, that they tended to focus on crystalline gels/liquids and eyelids and lenses. This is an interesting trend since those groups all consistently came up with the same analog sources. There are occasional deviations from this norm such as Group B's shark teeth concept but more groups stayed in the gel/liquid and eye concept area then those that moved out of that area. This may be due to directly searching for component analogs (lenses in this case). The groups using the generic search engine came up with different ideas all with a similar idea of gels and resolidifying materials and each concept was very similar to concepts generated within the same design group. Each group using the generic search engine reported similar concepts overall and each group's concepts were variations on the same thing many times. Group C and the Strategy Mapping Tool groups came up with lots of different concepts from many different analogs. Some analogs were used multiple times such as the African Clawed Frog which Group C did not use but 3 other groups did, but the majority of analogs were unique. These groups also showed a greater

tendency to change the way they solved the problem. Group C presented a concept that prevented damage while other groups using Method 3 generated concepts that forced the damage to occur in specially built areas and some groups made the lens readjust to the crack instead of repairing it. One group suggested making the lens a combination of several lenses and then just changing which one was in use. An interesting thing to note is that that many groups using Strategy Mapping generated at least one preventative concept and specifically mentioned that it was because the design tool differentiated between strategies relating to mission critical components and non-critical components. As a final note, nearly every analog found by the AskNature groups and the groups using a generic search engine were also in the Strategy Mapping Tool's analog pool at the time of the experiment.

CONCLUSIONS

An experiment was created to test the validity and usefulness of a Bio-Inspired Design Tool by Strategy Mapping. The tool was tested using eleven groups of engineering design students along with AskNature and no design tool for comparison purposes. The test was to create a solution to a design problem using Biologically-Inspired Design and the hypotheses were that the Strategy Mapping tool would allow for faster and easier concept generation in the design process over AskNature and easier integration of analogs into concepts. The results of the experiment indicate that the groups using the Strategy Mapping Tool found it easier to generate concepts, did so faster, and had an easier time integrating analogs into concepts when compared to AskNature and a search engine. However, those that used AskNature felt they benefitted more

from the use of BID than the other two methods potentially indicating a benefit from a refined user interface.

From the data collected in this experiment several conclusions can be drawn. First, respondents reported that the Strategy Mapping Tool helped to generate concepts easier and quicker than using AskNature or a search engine. The key difference between the Strategy Mapping Tool and AskNature is that the Strategy Mapping Tool concentrates on the strategies behind the analogs instead of the analogs themselves. This matches with the hypothesis that this difference was in some way useful to the design teams. The design tool leads groups to analogs and their strategies and in many cases, the tool presents multiple analogs. This may have allowed the design groups to see different ways of implementing the strategy from the outset thus laying the groundwork for multiple concepts. This could also lead to an increase in the speed by which the concepts are generated. Also there is no observed difference in the number of concepts generated from each method. In total Method 1 groups submitted 6 concepts, Method 2 submitted 9 and Method 3 submitted 13. While these numbers are different, it was noted that many groups only submitted 1 or 2 concepts but group members reported generating more. Since the data is collected anonymously, it is not possible to trace which questionnaire was in which group thus making a more concrete analysis impossible. Since an unknown number of concepts were generated the results on Question 2 can be taken as a direct measure of time spent generating those concepts without calculating a concept per time measurement. Question 2 asked how quickly group members felt the group generated concepts. The results suggest that groups were also able to more quickly hone in on concepts using the Strategy Mapping Tool than with any other method.

It was also noted during analysis that the Strategy Mapping Tool groups found unorthodox solutions from unexpected areas. For example, one group used the honey badger as an analog to fix the telescope lens. The honey badger exhibits fault adaptation when it is bitten by a venomous animal, thus introducing a harmful compound into the badger. The honey badger's body collects the venom in sacs which it can then later use in its own defense. The strategy for this analog is based around redirecting a fault into a location where it is less harmful or even beneficial and the students used this to create concept by which the lens broke in a specific location. The concept was based around manipulating the situation to ensure the fault occurred in a part where its effect was limited as is consistent with the strategy of the honey badger adaptation. Other examples include Group C's Wood Frog and American Shad analogs. Nearly every group using AskNature called out crystalline liquids, eyelids or eye lenses as analogs with examples such as the Nurse Shark teeth are the rare exception however very little overlap occurred with the groups using the Strategy Mapping Tool. This seems to indicate a relationship between Strategy Mapping and diversity of analogs selected. The Strategy Mapping Tool identifies strategies and supposes that the strategy is applicable to different problems in different circumstances. This result seems to indicate that groups using the Strategy Mapping Tool identified analogs with completely different characteristics, function and situations than the design problem they were provided.

The final major point of interest in the results is in the substantial increase in the group's ability to integrate their selected analog into a concept. The idea behind the Strategy Mapping Tool is that a strategy is more general than tactics and thus can be more readily applied to different, seemingly unrelated problems. With this in mind, we would therefore expect an increase in Question 4 since integrating a strategy is hypothesized to be easier than just an

analog. We see this result with a full point jump over the groups using AskNature. We can therefore conclude that strategies in some way make it easier to integrate the analog into a concept. Due to the limited scope of this experiment it is impossible to say much more beyond that. The diversity of analogs proposed by the groups using Strategy Mapping also lends credence to this theory. As mentioned before, nearly every analog used by the groups using a generic search engine and AskNature was available to the groups using Strategy Mapping however, there is very little overlap between the Strategy Mapping groups and the others. Also given that the same time frame was imposed, the Strategy Mapping groups chose analogs with far less in common with the design problem except for the strategy which implies that it was just as easy for a group to implement more diverse and divergent analogs than it was for a more traditional analog as found by the AskNature and search engine groups.

This experimental setup does have some problems that may be influencing the results. The first is the small sample size; there simply is not a significant base of data from which to draw reliable conclusions. It is expected that this leads to very low or very high scores unduly influencing the final numbers. It is not unreasonable to expect that some individuals were dissatisfied with some aspect of one of the methods and could provide lower scores because of it. Secondly, the perception-based form of the questionnaire could result in broad interpretation.

FURTHER WORK

During the testing process it was observed that there were some errors in the tool that were corrected. Some examples were questions that had the answers backwards. The “yes” answer was actually consistent with the “no” response and vice versa. This mistake leads to an

error in the design tool where the tool identified the wrong set of analogs. This was clarified by the groups asking for further information and the mistake was rectified without influencing the results. These errors are simple changes to the question context while some other questions had errors that involved moving branches around. Another change is based on the comments provided on the questionnaire. A vocabulary section has been added to the instructions that explain the terms and how they relate to one another. This caused some confusion initially but it was rectified during testing. Additional comments related to the presentation of the tool, which is currently in Excel. Later work will involve writing a script file that will make the tool much more useful and clear while maintaining its flexibility.

Outside of the experiment, it was noted during the assembly of the tool that many different strategies could be used to describe the same analog(s). With this in mind, a direction of further research could be in analyzing these strategies for the same analogs and determining a metric to determine which, if any, is optimal. This could be used to optimize the tool and/or to determine the optimal strategy for the situation the designer is dealing with. The next area of further work is the obvious expansion of the tool through more analogs and strategies. This would make the tool more relevant to more situations.

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FIGURE CAPTIONS LIST

TABLE CAPTIONS LIST

APPENDIX 1

Biologically Inspired Design Project

Project Summary: Each group will be asked to solve a design problem using Biologically Inspired Design (BID). Each group will be assigned a BID method to use in the design process and for selecting an analog. Groups will also fill out a feedback sheet to provide some other information about the design process for analysis. After 1 week each group will submit a design concept and filled out feedback sheet.

Design Problem: You are working on a new orbital telescope satellite and one of the major concerns with the design is the lens fracturing during loading and/or launch. Use BID to come up with a concept design to address this problem after the rocket transporting the satellite has lifted off (Use the Hubble Space Telescope as a model for the satellite if necessary and you are free to define how the rocket/launch mechanism and satellite behave after launch).

You can solve this problem however you want, so long as there is a biological analog corresponding to the design. Your design can function at any stage of the products life (Immediately after liftoff, after achieving orbit etc…).

The Analog: Each group must identify a biological analog corresponding to their final design. Groups may only search for this analog via the method assigned to them although additional

resources may be used to find more information about the analog. How the analog is reported depends on the method being used.

Final Product: Each group will turn in a summary of their design concept. Turn in sufficient material (summaries, drawings, critical calculations) so that someone who is not familiar with the concept can understand it. In addition, a feedback sheet will be provided on blackboard by Monday, September 28 and a completed feedback sheet is to be included with the concept. Concepts and feedback sheets can be turned in via email to the test coordinator or in his mailbox in the MEEG office.

Method 1: Method one is actually no method at all. Groups assigned this method are not provided any assistance and are not allowed to use any BID tools in search of analogs. The final analog chosen is to be reported by a providing a link to the Wikipedia page for the analog.

Method 2: Method two requires the use of the BID tool AskNature (http://www.asknature.org/) . Groups using this method are expected find their own information on how to use the tool. Analogs are to be reported by providing a link to the AskNature page.

Method 3: Method three uses the Strategy Mapping Design tool (provided on blackboard). Groups using this tool will also need the instructions and are free to ask Nick Huisman via email questions about how to use the tool. A tutorial for the tool will be performed in class. Analogs for this method can be provided with just the name.

APPENDIX 2

Strategy Mapping Tool Questionnaire

Circle the number that most appropriately matches your opinion on the answer to each question.

How difficult do you feel it was for your design group to generate concepts for the solution?

1	2	3	4	5
Not Difficult				Very Difficult

How quickly do you feel your design group able to generate concepts for the solution?

1	2	3	4	5
Very Slowly				Very Quickly

If your design group used a design tool, how much do you feel your group benefited from it?

1	2	3	4	5
				Heavily
Didn't Benefit				Benefitted

How easy was it to integrate the biological analog into a design concept?

1	2	3	4	5

Very Difficult Very Easy

Do you feel your group benefitted by using Biologically Inspired Design?

1	2	3	4	5
				Heavily
Didn't Benefit				Benefitted

Additional Comments:

Total number of hours spent generating concepts:

Note: Count group work time as the number of people in the group times the number of hours spent as a group

Total number of concepts generated:

APPENDIX 3

Group A Concepts

The first concept is based on the stem cells that are found in the human eye.

The human eye has retinal stem cells. These cells develop into fully functional eye cells and can be used to repair damaged eyes.

The situation that we are presented is a telescope lens that is going into space is cracked either in transport or once it is in space. Taking this natural function of the human eye and applying it to a telescope lens means filling the lens with a clear, thick fluid. Once the lens cracks, this fluid can fill the crack and harden once it is exposed to the outside air. This would form a seamless repair as the fluid just becomes part of the rest of the lens. The focal point would not be affected, and any additional cracks could continue to be easily repaired as long as there was fluid left.

Article: www.jwen.com/rp/articles/eyerepair.html

Expanding on the above idea, this biological lens could also be shielded and cleaned by a nictitating Membrane which would perform these tasks whilst maintaining visibility (Wikipedia, n.d.). This membrane would be a transparent ‘eyelid’ which would encase the lens when it needed protection and could also provide a windshield wiping effect if the lens required cleaning. It could also be used in conjunction with the previous concepts and could be used as the case enclosing the lens during times of repair.

Article: Wikipedia. (n.d.). Nictitating membrane. Retrieved from Wikipedia: https://en.wikipedia.org/wiki/Nictitating_membrane

This concept is modelled after how a human body repairs its self after a cut.

In this concept the repair will happen in stages just like the human body. First after the crack has happened, a case will enclose the lens and will be of the original curvature. This will act as the

platelets that come from a wound to stop the bleeding and remain on the surface of the skin. Next a clear liquid will be placed into the crack; this will represent the Proliferation phase of wound healing where new cells are being introduced to the wound. Finally, the liquid will harden and be of the same curvature and clarity of the original surface reflecting on how, in the maturation phase, the wound is sealed with scar tissue.

The third process was inspired by the regenerative processes of a newt.

In 2011 it was reported that a biologist at the University of Dayton had removed the eye lens of a newt eighteen times in order to test the regenerative properties of the animal. The test took 16 years and upon inspection the final regenerated eye was virtually identical to the original. In regard to the cracked satellite lens, we could treat the cracked lens as an analog for an injured eye and injected the damaged lens with an analog for stem cells in order to repair it to its original state. This would probably have to be done by heating the lens, applying the repair material, and melting it into the appropriate crystal structure to be of use in deep space viewing.

Article: http://www.nature.com/ncomms/journal/v2/n7/full/ncomms1389.html

This concept involves the use of an artificially engineered biological lens capable of viewing the visible and ultraviolet light spectrums. This ability to view both visible and ultraviolet light was inspired by birds and their ability to tap into the both light spectrums (Berger, 2012).
This lens would have to be frequently scanned for damages and defects and repair would be made by applying stem cells to the affected region which would then replicate the existing cells

in the damaged area. This idea arose from the regenerative abilities of planarians which use stem cells to regenerate lost body parts with the use of stem cells (Nguyen, n.d.).

For extra protection, this biological lens would also be shielded and cleaned by a nictitating Membrane which would perform these tasks whilst maintaining visibility (Wikipedia, n.d.). This membrane would be a transparent ‘eyelid’ which would encase the lens when it needed protection and could also provide a windshield wiping effect if the lens required cleaning. It could also be used in conjunction with the previous concepts and could be used as the case enclosing the lens during times of repair.

Group B Concepts

Concept 1:

Nurse sharks have several rows of teeth in their mouth at a time and when one falls out the next row flips down to take its place. Our concept is to design a system of lenses on the device that replace one another after one is damaged. This concept wouldn’t necessarily make the device last forever but it could extend the life of the device for the duration of the mission. Number of extra lenses would depend on the length of the mission.

http://www.asknature.org/strategy/6fd45d65d796eeace93dbc1def0e90db

Concept 2:

Human skin repairs itself when it is damaged by creating releasing new collagen and proteins that fill in the gap. Our concept is to design a lens with lots of tiny hollow fibers running through it that would release some sort filler that would release when a crack is found. The liquid in the fibers would fill the crack and then harden so the lens would be like new.

http://www.asknature.org/strategy/10f503d77742ad8ef09144b314760426

Concept 3:

Crocodiles use a special secondary lens to create a barrier between their seeing eye and water. This not only allows for better underwater vision but also provides protection. Following this concept, the telescope lens could use a replaceable exterior glass cover. This protective cover would be applied to the exterior of the lens and when it gets broken via debris, is removable and replaceable. This could be achieved either by repeated application or the replacement lens covers could have their own housing just outside the lens itself and rotate down into position, just like the crocodile.

Group C Concepts

CONCEPT #1

SELF-HEALING TELESCOPE

Group – Reuleaux

This concept was inspired by the Lithobates Rana Sylvaticus Wood Frog, native to the Alaskan territory of the United States. The idea is to have the lens of the telescope encapsulated between of two plastic plates, such that the plates will allow enough light to penetrate the lens with little to no loss in image quality. The lens on the telescope will be made of a special type of polymer that melts when a small amount of heat is applied to its surface, and will require a constant cool temperature to retain its shape and size. The cold temperature will be applied at the interface of the lens with the aid of a liquid nitrogen-filled coil which is wrapped around the circumference

of the plastic plates encapsulating the lens. Another coil will be placed in the same location as a heat transfer tool. Additionally, the plates will be polarized, such that an electric field will manifest between the plates and the lens. In the event that the lens fractures or breaks, a voltmeter will detect the sudden change in voltage, send a relay signal back to the telescope's computer, and shut off the liquid nitrogen flowing through the first copper coil. After that, the other copper coil will begin to apply just enough heat for a certain amount of time so that the lens transitions from a cracked solid to a viscous liquid. Liquid Nitrogen will then begin flowing through the coil and solidifying the lens back into its original shape without the fractured surface. The process is repeated for a number of cycles.

Similar to how the Wood Frog shuts off its organs during the winter and reactivates them at the presence of warm temperatures; the lens' structure will begin to shut off its original crystal lattice structure by melting at the instance of fracturing, while being restructured by the application of cold temperatures.

CONCEPT NUMBER 2

Readjust- Tier 1

Group – Reuleaux

American shad live in the Atlantic Ocean, but swim back to spawn in the fresh water of rivers. The major organ that regulates amount of salt water to fresh water is the kidneys. They have specialized gills to get rid of excess salt. These fish must take their time to slowly adapt to the change of salt water to fresh water environments. If they went from one extreme to the other it would be fatal.

This same concept of slowly readjusting to the new given environment is present in avoiding a fractured lens of the Hubble Telescope while loading or during launch. This design is simple but

effective to avoid fracture. The lens of the telescope is located inside a large cylinder. The lens for the telescope is slightly smaller diameter than the diameter of the cylinder. A spring mass damper system will encompass the circumference of the lens mounted to the inside of the walls of the cylinder. As loading and take off occurs, a damping effect will happen which creates an environment that allows the lens to essentially float. The lens will be able to absorb the shock and vibration of launch and take off while avoiding fracture. This design is a suspension system for the lens.

Based upon the lives of American shad that spawn to new environments, the lens of the telescope must be able to survive impulses to avoid mission failure. This suspension system will allow for sudden impulse, but absorbing the shock wave and saving the lens.

Concept #3

Regeneration Telescope

Snail, Achatinoidea

The design concept to fix a broken lens on a telescope is by regeneration. The concept replicates the characteristics of how a Achatinoidea snail replaces its shell when it cracks. The shell has multiple layers just like the snail and will secrete this type of plasma to replace the broken shell. The outer shell has a crystalline structure that is very brittle for strength in the material but hinders the sight of the telescope. The middle layer is more ductile to provide a cushion in between the outer layer and the soft bottom layer. The bottom layer is soft and provides the telescope with all of its seeing features. Upon fracture a vibration tool that is attached to the telescope is manually turned on to test the depth and width of the crack. Once the amount of loss from each layer is determined, a heat exchanger is turned on and the pre-determined amounts of each layer of plasma is secreted into the telescope lens. The heat exchanger is used to heat the

plasma needed to be secreted and the hardened plasma lens which will be heated into a liqid. The different densities of the plasma separate themselves in their liquid state and the telescope has thus been replaced.

Conclusion

In the first paper titles “Biologically Inspired Design Tool by Strategy Mapping the concept of a strategy and how it can relate to was introduced and followed by the development of a design tool using the concept of strategy. The concept of strategy is drawn primarily of military theory and relates to the intention of someone performing a task. This joins with the concept of tactics, which is how something is accomplished; to from a single way to describe how problems are solved. This results in the idea that a solution to a problem has two components, a strategy and tactics. The strategy contains, but is not limited to, the principles, ideas and decision making trends that are applied to the problem and the tactics describe how this strategy was implemented to solve the problem. This concept was further explored and it was shown that it can be applied to engineering design to help implement Biologically Inspired Design (BID). It is proposed that the strategies used in nature can be directly applied to engineering problems and are more useful than just identifying analogs for that problem. To test this hypothesis a design tool was develop that provides the designer with a set of analogs that relate to their design problem and the strategy that those analogs satisfy. This is accomplished by using a series of binary questions that the designer answers based off of their design problem. This identifies the strategy the designer wishes to use based off of the answers to the questions and then the tool provides the analogs from nature that utilize the same strategy. This process is called “Strategy Mapping”. Designers also have the freedom to change how they approach a problem to yield different strategies and analogs to use for inspiration.

The second paper described a method for attempting to validate the design tool and this method involved providing the Strategy Mapping tool and AskNature to several groups of design students, having the students use the tool to generate concepts for a design problem and then used a questionnaire based Likert Scale from 1-5 to rate the tools versus each other. AskNature

was chosen because, like the Strategy Mapping Tool, it seeks to provide a more generalized approach to BID and AskNature also presents it findings in the form of a database which is similar to the Strategy Mapping Tool. It was hypothesized that identifying strategies would be more helpful to design groups than just providing a set of analogs. A total of 11 design groups were provided with either the Strategy Mapping Tool (4 groups), AskNature (3 groups) or no tool (3 groups). The prompt for the design problem was that a satellite telescope was being designed and a concern in the design stage was that a crack might from in the lens during transport and liftoff. Students were then asked to generate concepts using BID and the assigned design tool to allow the satellite to adapt to the crack without assistance. The results of this experiment showed the those groups that used Strategy Mapping generated concepts faster, easier and had a much easier time integrating them into useable concepts. Since the idea of strategies was the most significant difference between AskNature and Strategy Mapping is tis therefore not unreasonable to conclude that strategies are more helpful to designers than simply providing analogs to the deign groups.

During this research several different areas for further investigation were identified. The first is that many strategies had more than one point of difference but since the tool used binary questions it only used one point of difference. This means that not every strategy was fully defined which opens up the area of looking into this and finding a way to fully describe each strategy. Related to this is the idea of also coming up with a more quantitative way of determining strategies. Strategies in this work were developed by comparing analogs and identifying points of difference in the intent of the analog which is not necessarily an easily replicated process and a more concrete, repeatable method would be very useful for further research. A second major area for further work is in finding ways to better implement the

strategies the tool provides. The tool currently only provides strategies but if abstraction techniques and other BID techniques are applied to the strategies instead of the analogs that may reveal novel and new ways for a designer to implement those strategies. This could lead to even more diversity in designs coming from the same analogs. Another variation on this idea is to fully describe how certain aspects of a strategy are implemented in nature. This could lead to a new set of processes and techniques that can be readily applied to any situation which would be of great benefit to designers and would allow for BID to be used potentially without a specific analog. Finally the design tool can be expanded to incorporate additional analogs and strategies or the idea of strategy mapping can be applied to different areas of design theory. This approach could lead to changes in the design process and a further quantifying of engineering design principles.

As a few closing thoughts a more concrete definition of strategy and tactics are provided in the form of axioms for potential expansion into an axiomatic design theory.

1. For any given problem, ω, that has a solution, μ, there exisits one or more strategies that, when applied to ω yield solution μ.
2. Any strategy that, when applied to a problem ω, yields solution μ, can be applied to problem η and yields solution ε.
3. A strategy is a design philosophy that is composed of, but not limited to, ideas, principles, decision making trends and constraints not listed in the problem statement.
    i. Note: Goals/Objectives are not part of a strategy; they are part of the problem statement.

ii. Constraints can be part of strategies or the problem statement. Constraints included in the strategy are consraints imposed by the designer in addition to any listed in the problem statement.

4. For any given strategy being applied to a problem, there exist a set of tactics which describe how the strategy is executed.
5. A strategy and set of tactics combine to form a solution to a problem.
6. Tactics are not unique to any given strategy and can be observed in conjunction with many different strategies.
7. In the case of a design hierarchy, a set of tactics can be used as a strategy for entities lower in the hierarchy.
8. All tactics used must satisfy every strategy above them in the hierarchy.

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Appendix

Strategy Mapping Tool Instructions

The objective of the tool is to match biological analogs to fault adaption problems by determining the strategy of both the analog and the problem. The things that this tool aims to provide to designers are 1) Provide suitable biological analogs and 2) Provide the strategy behind those analogs. In order to provide these the following steps must be taken.

1. Determine which of the following methods the adaptation will occur (Descriptions of each are provided) :

   Repair – The adaptation will occur by fixing the mechanism using existing components or components exterior to the system

   Replace – The adaptation will occur by having the mechanism create a replacement component

   Repurpose – The adaptation will occur by using other components to mimic the performance of the faulty component

   Reprogram – The adaptation will occur by changing the mechanisms programing to account for the faulty component

2. Open the tool and navigate to the sheet with the name matching the method chosen and a Tier of 1.
3. Navigate to the cell indicated begin
4. Follow the blue shaded path down until a Decision Box is reached. A Decision Box looks like this:

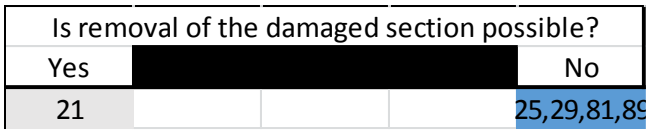

Figure 1: Image of a Decision Box

5. The Decision Box includes a binary question; select either yes or no as the answer. This will lead to either another blue path or a grey box.
6. If a blue path results from that answer, follow the blue path to the next decision box. If a grey box is reached, locate that number in the Number Key. If no number key is provided then the numbers in the grey box indicate the numbers of the relevant biological analogs, located in the appendix, for that particular method of adaptation.
7. The Number Key will either indicate a number or state "Proceed to Tier x" where x is another tier. If a number is provided, that number is the number of the biological analog that follows that strategy by that method. The biological analogs are provided in the appendix and are organized by method and numbered numerically. If the key indicates to proceed to another tier, collect the organ listed and the number of the next tier.
8. Navigate to the next tier and locate the organ indicated.
9. Repeat steps 3-8 until a grey box is provided but use the organ name as the start point instead.
10. Collect indicated biological analogs.

Vocabulary:

System - The overall system being designed

Mechanism - The subassembly the faulty component is a part of

Component - The specific part that has the fault

Factor - The fault that is occurring

Replace

1) Mexican Axolotl, Ambystoma mexicanum

The Mexican Axolotl is a salamander in the amphibian class. It can live 10 to 15 years in the wild but are considered endangered due to the water pollution, trading business, and being a food delicacy in Mexico ("Mexican Axolotls"). The Axolotl has a great ability of regenerating its limbs as true limbs, muscles, and differentiated cells, not as scar tissues.

After the limb is amputated a plasma clot forms and the epidermal cells from the stump migrate to cover the wound surface and form the obligatory wound epidermis. This layer continues to reproduce and forms the apical ectodermal cap. The cells under the apical ectodermal cap undergo dedifferentiation and genes that express differentiated tissues, such as MRF4 and myf5, are down-regulated and msxI, proliferating progress zone, is up-regulated (Gilbert). The undifferentiated cells beneath the apical ectodermal cap are called the regeneration blastema. These cells will multiply and differentiate into the structures of the limb by PAX7+ cells, which are regulated by TGF-beta1. Down-regulation of p53 is essential to form the blastema, and later on in the healing process up-regulation is needed for re-differentiation of the cells (Yun et al.). A major difference James W. Godwin found in Axolotl regrowth compared to mammalian healing is that the presence of macrophages and pro-inflammatory and anti-inflammatory cytokine signals in the blastema within hours of the amputation are required to stimulate and sustain regeneration. This allows for no tissue scarring and perfect regrowth of the limb.

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2) Snapping Shrimp or Pistol Shrimp, Alpheus heterochelis

The Snapping Shrimp can be found along the United States Atlantic Coast and in the Gulf of Mexico. It is characteristically seen with one large claw and another smaller pincer. It has the capability of growing out the smaller pincer if the big claw is detached and growing a smaller pincer in its place.

The Snapping Shrimp can detach its larger claw when in a fight or can get it amputated. The shrimp undergoes a molting process several times throughout its life to grow in size and to regrow its claws. The process includes 4 stages: postecdysis, intermoult, proecdysis, and ecdysis ("Moulting"). During the postecdysis stage the old exoskeleton has been shed and the new exoskeleton expands due to increased hemolymph volume from water influx ("Moulting") and later the exoskeleton hardens from calcium deposition. During the intermoult stage the water in the skeleton is used to create tissues, which cause the shrimp to become larger in size. This allows the smaller pincer to grow into the larger pincer, if need be. The stage also allows primary cell division and differentiation that results in the formation of basal papillae (Mykles). The proecdysis stage happens just before molting and allows for the calcium to be reabsorbed into the epidermal cells. During this stage the limb can grow and form the smaller pincer, although it takes 3 or more molting stages to become a mature claw (Ariane et al.). This stage can also develop the smaller pincer into the larger claw if it was amputated. The ecdysis stage begins with the old exoskeleton opening and ends when the crustacean escapes.

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3) Sea Cucumbers, *Holothuria glaberrima*

Sea Cucumbers can be seen all over the globe in oceans, preferably on the floor of deep oceans. They can live 5 to 10 years in the wild and can range from 0.75 in to 6.5 ft ("Sea Cucumbers"). They are known for being able to regenerate their radial nerve cord.

Radial nerve chords are made of etoneural (EN) and hyponeural (HN) bands separated by connective tissue (CT). If the Sea Cucumber was to injure its radial nerve cord (RNC) it would under axonal growth and then remodel itself to its original morphology. When the RNC is injured it would immediately cause fan-shaped stumps, which are caused by swelling of the EN band (Miguel-Ruiz et al.). Morulas are found to surge into the proximal end of the nerve stumps where they interact with RNC cell bodies and regrowing fibers. Spherulocytes are also found proximal to the nerve stump but decrease as the nerves are regenerated. RN1-labeled fiber bundles could be seen protruding from the stump toward the other stump along the substratum wall (Miguel-Ruiz et al.). In order for the fiber bundles to grow, the cells in between the stumps and in the fiber bundles underwent extreme cell division. The fiber bundles eventually grew enough to connect the two ends and make the RNC. Frayed fibers are believed to be peripheral nerves that could go into the EN and HN bands (Miguel-Ruis et al.). As more time passed the CT band could clearly be seen differentiated between the EN and HN bands from the surrounding tissues regenerating themselves through cell proliferation as well.

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4) Planarian, Planariidae

Planarians can be found in freshwater under rocks and debris. They are bilateral and sensitive to the light ("Planaria"). They have the remarkable capability of regenerating multiple, equal, new planarian when cut into various pieces.

Planarians have cells that are similar to embryonic stem cells in humans. Embryonic stem cells have the ability to differentiate into whatever type of cell the body needs. The large amount of cells in the Planarian help the animal regrow its body into a new, identical, normal looking planarian. Whenever it is cut into pieces a blastema will begin to form at the site of the wound. The blastema houses whitish cells that are in the embryonic-like state ("Planaria: A Window on Regeneration"). These cells will start multiplying and differentiating into tissues, bones, nerves, etc. to form the missing body part. Once the planarian has regrown its body part the blastema will disappear.

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5) Zebrafish, Danio rerio

Zebrafish can be found in the tropical fresh waters of northern India, northern Pakistan, Nepal, and South Asia (Hamel and Mercier). They can grow up to 4-5 centimeters in length and get their name from stripes on their body. Zebrafish are known for their ability of regenerating their heart.

Heart regeneration in Zebrafish is one topic that has had a lot of research because scientists believe that we can use their methods on humans. Researchers have found that after the heart is damaged the wound is sealed with a fibrin clot to stop the bleeding. In their paper, *The zebrafish as a model for complex tissue regeneration*, Matthew Gemberling and colleagues have found that the epicardium covers the clot and activates an analogous organ-wide response of raldh2 induction. Epicardial cells that have proliferated and surrounded the endocardium signal cardiomyocyte proliferation from pre-existing cardiomyocytes in the epicardium. RA, Tgf-beta ligands, lfg2, Shh, and platelet-derived growth factor (Pdgf) ligands are used in muscle regeneration in the endocardium (Amagai et al.). Gemberling, and colleagues, have also found that epicardial cells and Fgf signaling are used in vascularizing the regenerated muscles. Once the heart has reached maximum size the epicardium stops signaling for cardiomyocyte proliferation and vascularization, while the other factors in regeneration stop as well.

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6) Murphy Roths Large mice, MRL/MpJ laboratory mouse

Murphy Roths Large mice are a strain of mice found in laboratory settings. They are known for having a heightened wound healing and regeneration capability.

Murphy Roths Large mice have been found to use cells to re-epithelialize over dermal wound sites, which allows for a blastema to form under the layer (Edward). An inflammatory response involved neutrophils and macrophages expressing MMP-2, MMP-9, TIMP-2, and TIMP-3 (Heydemann). The high amount of these forms and proteins found in the MRL mice and not in the other mice seem to conclude that these are beneficial in helping the mice heal much faster. Transforming growth factor-beta signaling then allows for differentiation of cells and re-differentiation into cells the body needs to heal the mice. Metalloproteases are useful for making a conditional matrix from type IV collagen, fibronetin, entactin, and elastin in the extracellular matrix (Edward). Keratinocytes and fibroblasts migrated through the basement membrane by cellular and fibrillar debris which help the wound heal.

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7) Stick insects, *Sipyloidea sipylus*

Stick insects are found on every continent except Antarctica and range in size from 0.46 inch to 12.9 inches (Salmon). They are able to shed legs in order to escape predation and can regrow them.

Stick insects have the ability to regrow an amputated leg but only when they are in the nymph stage of growing. Stick insects cannot grow any larger unless it sheds its exoskeleton, which is the process called molting, and the reason why they can't regenerate a limb once they reach adulthood. The leg is usually broken off at the coxal-trochanteral joint, which is covered by a small black cap (Aldaz and Luis). The cap covers the imaginal disc made up of epithelial cells, which proliferate and make the leg grow (Aldaz and Luis). Once the body has reached its maximum size in the exoskeleton the insect will undergo molting. Their existing cuticles weakening at specific points along the body allows for air to seep under the exoskeleton and separate it from the new skin to cause molting (Aldaz and Luis). The stick insect will then hang upside down and crawl out of its exoskeleton inflating its new skin and causing it to get bigger. If the leg was lost in the first instar, developmental stage between molts, the leg will just be slightly smaller than the legs that were not amputated. If it was lost in the second or third instar it will be much smaller.

Salmon, J. T. "Stick Insects." *Tuatara: Journal of the Biological Society* 5.3 (1955): 77-79. *Victoria University of Wellington Library*. Web. 9 Nov. 2014. http://nzetc.victoria.ac.nz/tm/scholarly/tei-Bio05Tuat03-t1-body-d1.html

Aldaz, Silvia, and Luis M. Escudero. "Imaginal Discs." *Current Biology* 20.10 (2010): R429-431. *Cell Press*. Web. 11 Nov. 2014. www.cell.com/current-biology/abstract/S0960-9822(10)00291-5

8) Red blood cell regeneration in bodies

After an injury an animal could lose a lot of blood. In order for the animal to survive the kidneys produce and release erythropoietin, which is a hormone that stimulates the bone marrow to produce more red blood cells (Lichtin). It produces red blood cells from an unspecialized stem cell. This cell divides and becomes an immature red blood cell. After dividing again the cell turns into a mature red blood cell. Once the blood level rises back to the normal amount erythropoietin will stop being produced and production of red blood cells will go back to the normal speed.

Lichtin, Alan E. "Formation of Blood Cells." *The Merck Manuals: Home Edition*. Merck Manuals, Aug. 2014. Web. 14 Nov. 2014. http://www.merckmanuals.com/home/blood_disorders/biology_of_blood/formation_of_blood_cells.html

9) American Cockroach, Periplaneta americana

American cockroaches was originally from Africa but was introduced to all continents due to exploration (Barbara). They roam in tunnels and buildings where there is waste and easily acceptable food. American cockroaches have the ability of regenerating their leg if they were to get it amputated in some way.

Soon after the leg has been cut off or injured a blastema will form from the Wnt signal pathway (Nakamura et al.). This pathway initiates cells surrounding the wounded site to dedifferentiate and proliferate as undifferentiated mesenchyme cells. Three more signals help initiate and differentiate the cells in the amputated leg and they are Hh, Dpp, and Wg. The Hh signal helps organize growth and cell patterning in the regenerated leg (Nakamura et al.). The Dpp signal is found to differentiate the cells into chondrocytes that will form the leg joint (Nakamura et al.). Finally the Wg signal is found to differentiate the cells into the distal leg portions (Nakamura et al.). The undifferentiated mesenchyme cells would differentiate into chondrocytes to form other muscles of the leg. Endothelial cells will also form and create the blood vessels and nerves in the leg. The mesenchyme cells would also differentiate into epidermal cells that would create the exoskeleton of the leg and protect the internal parts. The epidermal cells would continually proliferate until the leg had grown back to its original size. Once the leg has grown to its maximum size the blastema would disintegrate and the cells would stop proliferating.

Barbara, Kathryn A. "American Cockroach." *Featured Creatures*. University of Florida, June 2000. Web. 13 Nov. 2014.

http://entnemdept.ufl.edu/creatures/urban/roaches/american_cockroach.htm

Nakamura, T., T. Mito, T. Bando, H. Ohuchi, and S. Noji. "Molecular and Cellular Basis of Regeneration and Tissue Repair." *Cellular and Molecular Life Sciences*65.1 (2008): 64-72. *Deepdyve*. Web. 13 Nov. 2014. https://www.deepdyve.com/lp/springer-journals/molecular-and-cellular-basis-of-regeneration-and-tissue-repair-nZIobAHySr/3

10) Dolphins

Dolphins live in oceans closer to the equator than the North or South poles. They can range in size from 4 feet to 25 feet in length ("Basic Facts About Dolphins"). Dolphins have the unique ability of regenerating tissue after getting bit by a shark or injured from variable circumstances.

Dolphin healing and blubber regeneration has not been researched very much as of yet, although Dr. Michael Zasloff, a surgeon and researcher at Georgetown University, believes that this topic would be beneficial in researching. Dr. Zasloff suggests that after the dolphin is bitten or injured it undergoes a diving reflex. The deep dive diverts blood away from the periphery of the body, which could allow quick blood clotting at the injured site and help the dolphin from loosing too much blood (Langlois). The dolphin also makes organohalogens, which are antimicrobial compounds in/around the blubber to keep the deep wound from get infected (Langlois). Finally Zasloff suggests that the animal undergoes regeneration of blubber with adipocytes, collagen, elastic fibers, and potential stem cells (Langlois). He believes that it is regenerated and not just healed because of the fact that the blubber looks the same as the uninjured blubber. Dolphin's ability to regenerate and heal has not been backed up by research yet but the possibility of regeneration will influence people to do more research.

"Basic Facts About Dolphins." *Dolphin*. Defenders of Wildlife, 2014. Web. 20 Nov. 2014. http://www.defenders.org/dolphin/basic-facts

Langlois, Mareen. "Shark Bites No Match For Dolphins' Powers Of Healing." *Health News from NPR*. NPR, 25 July 2011. Web. 20 Nov. 2014. http://www.npr.org/blogs/health/2011/07/26/138677504/shark-bites-no-match-for-dolphins-powers-of-healing

11) Hairy Frog, Trichobatrachus robustus

Hairy frogs are found in the Central African country Cameroon. They can be found in rainforests and their tadpoles are found in freshwater (“Trichobatrachus Robustus"). Hairy frogs have the ability to break their bone through the skin to produce a claw on their back foot and then heal itself.

When not threatened, the frogs bone lies within the flesh connected to a small, bony nodule by collagen. There is also a muscle that resides under the bone and connects to the lower half of the ‘claw’ (Young). When the frog is threatened it contracts the muscle, which breaks the collagen bond formed between the nodule and bone. This in turn allows the bone to be pulled down and puncture through the connective tissue and skin to form the ‘claw’ (Young). It is not know how the ‘claw’ is retracted back into the skin but researchers believe it is done passively as the muscle relaxes (Young). Once the claw is back in the skin, the collagen bond presumably reforms by fibroblasts invading the region and producing the protein, vimentin, which is a marker for mesodermal cells that helps to produce muscle. They also transform to produce epithelia to help in tissue repair. The skin also heals very quickly due to the fact that it is an amphibian. Frogs are known to have peptides called magainins that are antifungal, antiparasitic, antibiotic, and antiviral, which helps the wound from getting infected and slowing the healing process (“A World Without Amphibians”). Frogs heal quickly by being able to switch on angiogenesis, which stimulates blood vessel growth (Queen’s University, Belfast). They are also able to heal their skin quickly through regeneration. The wound undergoes immediate hemostasis to stop the blood loss. Wounds are closed by epidermal cells migrating to the site, joining together through

tight junctions, and forming two or three layers (Kawasumi et al.). Dedifferentiation causes mononuclear cells to infiltrate the site and produce mesenchymal cells to repair the wound. Re-differentiation occurs and produces the skin and exocrine glands.

"Trichobatrachus Robustus." *Eol*. Encyclopedia of Life, 2011. Web. 20 Nov. 2014. http://eol.org/pages/331425/details

"A World Without Amphibians." *Frogs: The Thin Green Line*. PBS, 28 Mar. 2009. Web. 20 Nov. 2014. http://www.pbs.org/wnet/nature/frogs-the-thin-green-line-a-world-without-amphibians/4852/

Yong, Ed. "'Wolverine' Frogs Pop Retractable Claws from Their Toes." Web log post. *'Wolverine' Frogs Pop Retractable Claws from Their Toes*. Science Blogs, 27 May 2008. Web. 20 Nov. 2014. http://scienceblogs.com/notrocketscience/2008/05/27/wolverine-frogs-pop-retractable-claws-from-their-toes/

Queen's University, Belfast. "Scientists unlock potential of frog skin to treat cancer." ScienceDaily. ScienceDaily, 7 June 2011. Web. 20 Nov. 2014. http://www.sciencedaily.com/releases/2011/06/110606181137.htm

Kawasumi, Aiko, Natsume Sagawa, Shinichi Hayashi, Hitoshi Yokoyama, and Koji Tamura. "Wound Healing in Mammals and Amphibians: Toward Limb Regeneration in

Mammals." *Current Topics in Microbiology and Immunology* 367 (2012): 33-49. *Springer-Verlag Berlin Heidelberg*. Web. 20 Nov. 2014. www.springer.com/cda/content/document/cda_downloaddocument/9783642358098-c2.pdf?SGWID=0-0-45-1388207-p174803797

12) Brittle Stars, Amphuira filiformis

Brittle Stars are similar to sea stars but have a smaller central disk, which may be under one inch. The specimen may grow from under an inch to 10 times that length (De Kluijver and Ingalsuo). They live in the North, Scandinavian, and Mediterranean seas. Brittle Stars are able to reproduce an arm if it was amputated.

The brittle star undergoes post autotomy after getting its arm amputated. Once the arm has been amputated a blastema is formed by undifferentiated pluripotent cells and dedifferentiated myocytes (Czarkwiani et al.). Re-differentiation of the cells into muscle and skeletal structures start to divide into metameric units that added onto the proximal end. The arm continues to differentiate and add on more metameric units until there are pronounced muscle and skeletal structures in the newly regenerated arm. The spines and podia are formed below the distal growth zone from buds (Czarkwiani et al.). Podia are specifically formed from the elongation of the radial water canal to allow for the water vascular system to interact with the new arm (Czarkwiani et al.).

De Kluijver, M. J., and S. S. Ingalsuo. "Macrobenthos of the North Sea - Echinodermata." *Marine Species Identification Portal : Amphiura Filiformis*. Key of Nature, 2004. Web. 20 Nov. 2014. http://species-identification.org/species.php?species_group=echinodermata&id=91

Czarkwiani, Anna, David V. Dylus, and Paola Oliveri. "Expression of Skeletogenic Genes during Arm Regeneration in the Brittle Star Amphiura Filiformis." *Gene Expr Patterns* 13.8 (2013): 464-72. *NCBI*. Web. 20 Nov. 2014. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3838619/

13) Brown ghost knifefish, Apteronotus leptorhynchus

Brown ghost knifefish originated in South American rivers (Glass). These fish are able to have around 100,000 cells in the proliferation phase within any 2-hour period (Glass). The Brown ghost knifefish has the ability of regenerating its central nervous system (CNS).

Brown ghost knifefish have proliferation zones located all over there body. These zones are continually producing new cells that can differentiate into a number of target cells. The new cells migrate to the target region with the help of radial glial fibers (Zupanc). Once at the destination apoptosis takes control and kills the damaged or unresponsive cells while the new cells attach to the designated spot. A neuropeptide called somatostatin is up-regulated in a specific spatio-temporal fashion after lesions are formed to initiate proliferation of cells from the zones to turn into the necessary cells to fix the CNS (Zupanc). Once the CNS has been fixed the cells will stop proliferating until they are needed again.

Glass, Spencer. "Knifefish Knowledge." *Knifefish Knowledge*. Coast Tropicals, 2014. Web. 20 Nov. 2014. http://www.fishchannel.com/freshwater-aquariums/species-info/knifefish/knifefish-knowledge.aspx

Zupanc, GK. "Adult neurogenesis and neuronal regeneration in the central nervous system of teleost fish." *Brain Behav Evol* 58.5 (2001): 250-75. *NCBI*. Web. 20 Nov. 2014. http://www.ncbi.nlm.nih.gov/pubmed/11978945

14) Japanese Spiky Sea Cucumber, Apostichopus japonicus

Japanese Spiky Sea Cucumbers are found in the Northwest Pacific ocean. It is currently on the Endangered species act after being exploited for its meat ("Apostichopus Japonicus"). They have the ability to eviscerate their internal organs to escape predators and then regenerate the missing body parts.

To evade predators, Apostichopus japonicas' expels its internal organs through the wall and anal opening except for the cloaca, pharynx, and esophagus (Odintsova et al.). Two rudiments, which are undeveloped or immature part or organ that can develop into an organ or limb, develop from the esophagus and cloaca (Odintsova et al.). The peritoneal, myoepithelial, and nerve cells in the esophagus and cloaca undergo dedifferentiation and then proliferate into more cells that are similar to stem cells. These cells migrate and re-differentiate into cells that will make up the two rudiments and the organs that were lost. As the rudiments grow they fuse together to form a single rudiment that will connect and form the continuous digestive system.

"Apostichopus Japonicus." *Apostichopus Japonicus (Japanese Spiky Sea Cucumber)*. The IUCN Red List of Threatened Species, Mar. 2014. Web. 23 Nov. 2014. http://www.iucnredlist.org/details/180424/0

Odintsova, N. A., I. Yu Dolmatov, and V. S. Mashanov. "Regenerating Holothurian Tissues as a Source of Cells for Long-term Cell Cultures." *Marine Biology* 146 (2005): 915-21. *Academia.edu*. Web. 23 Nov. 2014.

http://www.academia.edu/2044914/Regenerating_holothurian_tissues_as_a_source_of_cells_for_long-term_cell_cultures

15) Common Octopus, Octopus vulgaris

Octopi are found closer to tropical islands and the equator. They range in size from 12 to 36 inches and weigh from 6.6 to 22 pounds (“Common Octopuses”). Octopi are able to regenerate their arm if it was severed or lost to evade an attacker.

After the arm is severed a blastema will start to form at the very end where it was cut. The blastema enclosed mesenchymal cells, which allowed for the arm to grow back (Courage). Stem cells and blood vessels also swarmed to the site within the first three days to help rebuild the arm (Courage). There were also cells from the remaining arm that dedifferentiated and redifferentiated as the arm grew to form the muscles, suckers, chromatophores, and nervous system. AChE has been found to be key in helping the octopi regenerate its arm. It was found to accelerate cell proliferation, differentiation, and apoptosis (Fossati et al., p. 93-99). AChE would increase during cellular multiplication and was at its highest during myogenesis (Fossati et al.). The AChE would decrease during histogenesis and reestablishment of the structures. Once all of the structures in the arm were regenerated the cells would stop proliferating and the blastema would disintegrate.

"Common Octopuses." *Common Octopuses, Common Octopus Pictures, Common Octopus Facts - National Geographic*. National Geographic, 2014. Web. 21 Nov. 2014. http://animals.nationalgeographic.com/animals/invertebrates/common-octopus/

Fossati, Sara Maria, Francesca Carella, Gionata De Vico, Fabio Benfenati, and Letizia Zullo. "Octopus Arm Regeneration: Role of Acetylcholinesterase during Morphological Modification." *Journal of Experimental Marine Biology and Ecology* 447 (2013): 93-99. *Science Direct*. Web. 21 Nov. 2014. http://www.sciencedirect.com/science/article/pii/S0022098113000671

Courage, Katherine Harmon. "How Octopus Arms Regenerate With Ease." Web log post. *Scientific American*. Scientific American, 28 Aug. 2013. Web. 21 Nov. 2014. http://blogs.scientificamerican.com/octopus-chronicles/2013/08/28/how-octopus-arms-regenerate-with-ease/

Fossati, S. M., S. Candiani, M. T. Nodi, L. Maragliano, M. Pennuto, P. Domingues, F. Benfenati, M. Pestarino, and L. Zullo. "Identification and Expression of Acetylcholinesterase in Octopus Vulgaris Arm Development and Regeneration: A Conserved Role for ACHE?" *Molecular Neurobiology* (2014): n. pag. *NCBI*. Web. 23 Nov. 2014. http://www.ncbi.nlm.nih.gov/pubmed/25112677

16) Deer, Cervidae

Deer can be found in the entire world in different environments, except in Australia (“Deer Fact Sheet”). Deer are able to regenerate their antlers every year after they shed their previous antlers.

At first researchers believed that a blastema formed and dedifferentiation of cells took place and now they have found that it is not so. The shedding of the antlers has been linked to the hormonal changes that the male undergoes throughout the year. When he has low testosterone levels the antlers will fall off from the pedicle on the deer’s head. The antler is made up of bone, cartilage, skin, blood vessels, and nerves, which makes it different from horns. The pedicle must regenerate the antler with pedicle periosteum (PP), which are comparable to stem cells in humans (Li). PP cells will proliferate and differentiate into the cartilage and bone of the antler (Li). As more cells differentiate the antler continues to grow until a certain point, which is currently being studied. It is also currently not clear as to how the skin, blood vessels, and nerves are formed but the PP cells seem to stimulate the differentiation of cells for those specific functions.

"Deer Fact Sheet." *DEER FACT SHEET* (n.d.): n. pag. *Get Active for Animals*. World Animal Foundation, 2014. Web. 23 Nov. 2014. http://www.worldanimalfoundation.net/f/Deer.pdf

Li, Chunyi. "Deer Antler Regeneration: A Stem Cell-based Epimorphic Process." *Birth Defects Research* 96.1 (2012): 51-62.*Wiley Online Library*. Web. 23 Nov. 2014. http://onlinelibrary.wiley.com/doi/10.1002/bdrc.21000/abstract

17) Colonial Sea Squirt, Botrylloides leachi

Colonial Sea Squirts can be found in the Atlantic Ocean from Norway to the Mediterranean. They can have 8 to 16 branched tentacles and each zooid can reach up to 3 millimeters long (Olwen). They have the ability of regenerating their whole body from a tiny blood vessel.

Colonial Sea Squirts can regenerate their entire body systemically in blood vessels. Buds are formed from pluripotent blood cells within the vasculature fragments of the blood vessel (Rinkevich et al.). Changes surrounding the bud formed a blastula like structure that would help house the dividing cells. The pluripotent blood cells will proliferate to increase the size of the bud. After a couple days two elongated double-walled folds would fold into the thick vesicle wall that had been formed and create gill slits. They would also extend inward dividing the structure into 3 chambers creating the central pharyngeal and a pair of atrial chambers (Rinkevich et al.). The bud would continue to grow and regenerate internal organs for the sea squirt. Retinoic acid (RA) has been found to regulate the development of the body by regulating cell differentiation. If RA is inhibited or interfered the body will not regenerate or will cause bud malformations (Rinkevich et al.).

Olwen Ager. *Botrylloides leachii*. A colonial sea squirt. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme. 2008. Plymouth: Marine Biological Association of the United Kingdom. Web. 23 Nov. 2014. http://www.marlin.ac.uk/speciesinformation.php?speciesID=2790

Rinkevich, Yuval, Guy Paz, Baruch Rinkevich, and Ram Reshef. "Systemic Bud Induction and Retinoic Acid Signaling Underlie Whole Body Regeneration in the Urochordate Botrylloides Leachi." *PLOS Biology*. PLOS, 6 Mar. 2007. Web. 25 Nov. 2014. http://www.plosbiology.org/article/info%3Adoi%2F10.1371%2Fjournal.pbio.0050071

18) Painted turtle, Chrysemys picta

Painted turtles can be found in Canada, United States and Mexico (Van Dijk). These turtles live near rivers or marshes that are shallow but full of vegetation. Painted turtles have the ability of regenerating the scutes on their shells to allow for growth and to replace damaged shell sections.

At the end of the growing season keratinocytes directly beneath the old scute layer produce thin alpha-keratin cells that form a scission layer beneath the old stratum corneum (Alibardi). During the winter season the cells remain in the germinative layer of the carapace and plastron (Alibardi). The next spring new beta-keratin cells are produced beneath the scission layer. The epidermis under the scutes produces thymidine and histidine, while the corneous layer under the scission layer produces lipids, which forms the new layer of scute and help the old scute flake off (Alibardi). So as long as the site where the shell was injured can still produce keratinocytes a new piece of shell will be able to generate and replace the damaged portion.

Van Dijk, P.P. *Chrysemys picta*. The IUCN Red List of Threatened Species. Version 2014.3, 2013. Web. 27 Nov. 2014. http://www.iucnredlist.org/details/163467/0

Alibardi, L. "Proliferation in the Epidermis of Chelonians and Growth of the Horny Scutes." *Journal of Morphology* 265.1 (2005): 52-69. *NCBI*. Web. 25 Nov. 2014. http://www.ncbi.nlm.nih.gov/pubmed/15880409

19) Italian crested newt, Triturus carnifex

Italian crested newts can be found in Europe, which includes Serbia and Switzerland (Antonio et al.). Newts are capable of lens regeneration if they were ever to damage the lens.

After the lens is damaged pigment epithelial cells (PECs) of the dorsal and ventral iris re-enter into the cell cycle (Tsonis et al.). This means that they dedifferentiate and proliferate into cells that will re-differentiate into lens cells. Hyperphosphorlated form of Retinoblastoma (Rb) is expressed in the PECs of the iris and is key in regulated the cell cycles (Tsonis et al.). The PECs de-differentiate by shedding the pigment with the help of macrophages (Tsonis et al.). A lens vesicle is formed from the de-differentiated cells and elongation and re-differentiation of the cells creates lens fibers, while the anterior cells become the lens epithelium (Tsonis et al.). While the PECs are regenerating the new lens the extracellular matrix inside the vitreous chamber is released and fills in the aqueous chamber as well. The matrix slowly arranges itself into sheets and clears a path in the aqueous chamber (Tsonis et al.). There are also membranes being formed which will eventually mediate the attachment of the lens to the irises (Tsonis et al.).

Antonio Romano, Jan Willem Arntzen, Mathieu Denoël, Robert Jehle, Franco Andreone, Brandon Anthony, Benedikt Schmidt, Wiesiek Babik, Robert Schabetsberger, Milan Vogrin, Miklós Puky, Petros Lymberakis, Jelka Crnobrnja Isailovic, Rastko Ajtic, Claudia Corti. *Triturus carnifex*. The IUCN Red List of Threatened Species. Version 2014.3, 2009. Web. 27 Nov. 2014. http://www.iucnredlist.org/details/59474/0

Tsonis, Panagiotis A., Mayur Madhavan, Emily E. Tancous, and Katia Del Rio-Tsonis. "A Newt's Eye View of Lens Regeneration." *The International Journal of Developmental Biology* 48 (2004): 975-80. *The International Journal of Developmental Biology*. Web. 25 Nov. 2014. http://www.ijdb.ehu.es/web/paper.php?doi=10.1387/ijdb.041867pt

20) Human, Homo sapiens

If you were to cut your fingernail too short or it was to get ripped off the fingernail would be able to regrow. There are three major parts that are needed for the nail to regrow: the matrix, cuticle, and lunula. The matrix is the root of the nail. It is constantly making new cells that scientists call nail stem cells (Young). These cells pack together and push up through the skin and die as they are pushed out into view ("How Nails Grow"). The cuticle protects the matrix from germs. The lunula, which is the whitish, half-moon shape that you can see at the base of your fingernail, is part of the matrix ("How Nails Grow"). The fingernail is continually being regenerated but is most prominent when the fingernail gets ripped off.

"How Nails Grow." *How Nails Grow*. American Academy of Dermatology, 2014. Web. 25 Nov. 2014. https://www.aad.org/dermatology-a-to-z/for-kids/about-nails/how-nails-grow

Young, Ed. "Finger Regeneration: Stem Cells In Fingernails May Be Key To Regrowing Limbs, Scientists Say." *The Huffington Post*. TheHuffingtonPost.com, 13 June 2013. Web. 25 Nov. 2014.

http://www.huffingtonpost.com/2013/06/13/finger-regeneration-stem-cells-fingernails-limbs_n_3434196.html

21) Human, Homo sapiens

Over the years humans have become more technologically advanced. This has helped to create things and heal animals, which could not have been possible 50 years ago. Scientists have found that humans are also capable of regenerating a major portion of their liver if it was damaged.

Once there has been damage to the liver able hepatocytes will start to proliferate near the site damaged site. Various signals are required to initiate and control the proliferating and differentiating process, such as c-Jun, signal transducer and activator of transcription 3, CAAT enhancer-binding protein beta, and cAMP-responsive element modulator (Out et al.). Macrophages will also migrate toward the necrotic site and clear the liver of the dead cells so the new cells that are being produced can work properly (Hoehme et al.). Once all of the dead cells are removed the macrophages will disperse to other parts of the body. mRNA also increases in production so the cells are able to differentiate into the different parts of the liver (Hoehme et al.). Once the liver has recovered its density and is able to perform properly hepatocyte replication will cease.

Otu, Hasan H., Kamila Naxerova, Karen Ho, Handan Can, Nicole Nesbitt, Towia A. Libermann, and Seth J. Karp. "Restoration of Liver Mass after Injury Requires Proliferative and Not Embryonic Transcriptional Patterns."*The Journal of Biological Chemistry* 282 (2007): 11197-1204. *The Journal of Biological Chemistry*. Web. 25 Nov. 2014. http://www.jbc.org/content/282/15/11197.full

Hoehme, Stefan, Marc Brulport, Alexander Bauer, Essam Bedawy, Wiebke Schormann, Matthias Hermes, Verena Puppe, Rolf Gebhardt, Sebastian Zellmer, Michael Schwarz, Ernesto Bockamp, Tobias Timmel, Jan G. Hengstler, and Dirk Drasdo. "Prediction and Validation of Cell Alignment along Microvessels as Order Principle to Restore Tissue Architecture in Liver Regeneration." *PNAS*107.23 (2010): 10371-0376. *Proceedings of the National Academy of Sciences of the United States of America*. Web. 25 Nov. 2014. http://www.pnas.org/content/107/23/10371.full

22) Blue King Crab, Paralithodes platypus

Blue King Crab can be found off the coast of Japan, Russia, and Alaska (“Blue King Crab”). If fully grown, they can be the largest of all crabs. Blue King Crab have the ability of regenerating the leg if it was to loose its leg by autonomy or from an accident.

Crabs are only able to regenerate their legs as long as they are still molting. Molting is the process that allows the crab to shed their outer shell so the crab can get bigger and repair itself. There is a specific fracture plane that the leg is detached from. Once the leg has been cut off or lost, a membrane will form over the joint where the leg was lost and encloses the newly forming bud (Zinski). The membrane is made from the epithelial cells that surround the wound site and proliferate to cover it. Crabs get bigger by absorbing seawater and replacing it with protein after the crab has gone through the molting process (Stevens). The new bud also gets larger from protein replacing the water near the bud. It will take around three molts to grow the leg back to its original size, depending on how big the leg was before the detachment.

"Blue King Crab." *Blue King Crab Species Profile, Alaska Department of Fish and Game*. Alaska Department of Fish and Game, 2014. Web. 27 Nov. 2014. http://www.adfg.alaska.gov/index.cfm?adfg=bluekingcrab.main

Zinski, Steven C. "Autotomy & Regeneration." *The Blue Crab Archives*. Bluecrab.info, 2006. Web. 27 Nov. 2014. http://www.bluecrab.info/autotomy.html

Stevens, Bradley G. "Molting: How Crabs Grow." *AFSC/RACE*. NOAA Fisheries, 2014. Web. 27 Nov. 2014.

http://www.afsc.noaa.gov/Kodiak/shellfish/cultivation/crabGrow.htm

23) Immortal jellyfish, Turritopsis nutricula

Immortal jellyfish were discovered in the Mediterranean Sea in 1883. When they are fully grown they are about the size of a human pinky nail (Than). The immortal jellyfish has the amazing ability of reverting itself back into the polyp stage of a jellyfish.

If the immortal jellyfish is stressed environmentally it has the ability of returning to the polyp stage so it can continue the line and pass on the genes. It does so by resorbing their bells and tentacles and sinking to the ocean floor to form the polyp (Kong). The jellyfish cells are transformed in the process into various other younger cells such as nerve cells, oocytes, or muscle cells (Than). Once the conditions become more favorable for growth the polyp will start to grow and become a mature immortal jellyfish again, which is able to reproduce.

Kong, Nikki R. "Chasing Immortality." *Chasing Immortality- The Berkeley Science Review*. The Berkeley Science Review, 22 Apr. 2013. Web. 27 Nov. 2014. http://berkeleysciencereview.com/article/chasing-immortality/

Than, Ker. ""Immortal" Jellyfish Swarm World's Oceans." *National Geographic*. National Geographic Society, 29 Jan. 2009. Web. 27 Nov. 2014. http://news.nationalgeographic.com/news/2009/01/090130-immortal-jellyfish-swarm.html

24) Snail, Achatinoidea

Snails can be found on every continent, except Antarctica, and even in the oceans. They are herbivores and use microscopic teeth on their tongue to shred their food (“Snail”). Snails have the ability of building new layers of their shell so that a crack or break could be covered up by new shell before it hurts the snail.

The snail uses various cells to create specific layers of their shell. At the rim of the shell’s mouth there are transversal cells that secrete calcareous matter that will solidify into prisms or plate crystals (Nordsleck). The prism layer is the ostracum and other cells that secrete organic skin made of conchin cover it (Nordsleck). The last layer of cells cover the entire mantle on the inside and it adds amorphous calcium carbonate material to thicken the shell wall (Nordsleck). Snails are continually building and repairing their shells with the amorphous matter and you can see distinctly where they have been hurt from the different pigment given off by the amorphous matter.

"Snail." *Snail (Achatinoidea)*. A-z-animals.com, 2013. Web. 27 Nov. 2014. http://a-z-animals.com/animals/snail/

Nordsleck, Robert. "The Gastropod Shell- Part1." *Snails and Slugs (Gastropoda)*. The Living World of Molluscs, 2013. Web. 27 Nov. 2014. http://www.molluscs.at/gastropoda/index.html?/gastropoda/morphology/shell.html

25) Zebrafish, Danio rerio

Zebrafish can be found in the tropical fresh waters of northern India, northern Pakistan, Nepal, and South Asia. They can grow up to 4-5 centimeters in length and get their name from stripes on their body (Hamel & Mercier). Zebrafish also have the remarkable ability of liver regeneration.

After the liver in the Zebrafish has lost hepatocytes from sort of injury, biliary cells have been found to migrate to wound site. The biliary cells dedifferentiate through a process that was initiated by Notch signaling, which in turn activated cholangiocytes to dedifferentiate the cells (He et al.). Once the cells dedifferentiated they would proliferate and re-differentiate into hepatocytes. The hepatocytes would then attach to liver and gradually increase the livers size. Once the liver was at its maximum size the biliary cells would stop dedifferentiated and disperse back to where it came from.

Hamel, J.-F. & Mercier, A. *Apostichopus japonicus*. The IUCN Red List of Threatened Species. Version 2014.3, 2013. Web. 27 Nov. 2014.
http://www.iucnredlist.org/details/180424/0

He, J., H. Lu, Q. Zou, and L. Luo. "Regeneration of Liver after Extreme Hepatocyte Loss Occurs Mainly via Biliary Transdifferentiation in Zebrafish." *Gastroenterology* 146.3 (2014): 789-800. *NCBI*. Web. 28 Nov. 2014.
http://www.ncbi.nlm.nih.gov/pubmed/24315993

26) Catfish, Siluriformes

Catfish can be found at the bottom of freshwater habitats on every continent in the world besides Antarctica (Goss). They have barbels, whisker like structures, which contain the taste buds needed for the animal to find its food. If the barbel was to fall of or get cut off the catfish has the ability to regenerate their barbels back to their normal structure.

After the barbel is damaged a blastema made of chondroblasts form over the rod. The thick perichondrium that surrounds the rod becomes thinner as some of its cells are moved into the blastema as well (Goss). The blastema cells proliferate and differentiate into the cartilaginous rod (Goss). Nerve fibers and cells to make the blood vessels have been found to move towards the regenerating site and proliferate as well. Taste buds also differentiate in the epidermis as the rod is regenerating (Goss). Cells will continue to proliferate and differentiate until the barbel has fully grown.

Goss, Richard J. "Regeneration in Fishes." *Principles of Regeneration*. New York: Academic, 1969. 113-37. Print.
https://books.google.com/books?id=P_QgBQAAQBAJ&pg=PA130&lpg=PA130&dq=how+do+catfish+regrow+their+barbels&source=bl&ots=n4OQydAQyR&sig=RODE0etCsAPoPOcBHDyQDvOf6Rs&hl=en&sa=X&ei=eWCrVN2EMYGxggTg7YHABw&ved=0CDsQ6AEwBTgU#v=onepage&q=how%20do%20catfish%20regrow%20their%20barbels&f=false

27) American alligator, Alligator mississippiensis

The American alligator can be found in the southeastern parts of the United States (“American Alligators”). It has been found that American alligators are able to regenerate their teeth if injured or lost.

The American Alligator generates a replacement tooth in three steps: pre-initiation stage, initiation stage, and growth stage. During the pre-initiation stage you can see a functional tooth, a replacement tooth, and the undifferentiated dental lamina (Wu et al.). The dental lamina has an enlarged structure where the odontogenic stem cells are housed. During the initiation stage these cells start to proliferate and undergo morphogenesis to become the tooth organ components during the growth stage (Wu et al.). The growth stage also allows the previous functional tooth to be lost and the first replacement tooth to take its place while the next tooth is being generated. In order for the alligator to be able to continually regenerate teeth the outer enamel epithelium on the youngest replacement tooth must split to form another dental lamina (Wu et al.). Some of the stem cell niche needs to be retained in the dental lamina to regenerate the next tooth, if not then the alligator will stop producing new teeth.

"American Alligators." *National Geographic*. National Geographic Society, 2014. Web. 27 Nov. 2014.
http://animals.nationalgeographic.com/animals/reptiles/american-alligator/

Wu, Ping, Xiaoshan Wu, Ting-Xin Jiang, Ruth M. Elsey, Bradley L. Temple, Stephen J. Divers, Travis C. Glenn, Kuo Yuan, Min-Huey Chen, Randall B. Widelitz, and Cheng-Ming Chuong. "Specialized Stem Cell Niche Enables Repetitive Renewal of Alligator Teeth." *PNAS* 110.22 (2013): E2009-2018. *Proceedings of the National Academy of Sciences of the United States of America*. Web. 29 Nov. 2014.

http://www.pnas.org/content/110/22/E2009.short

28) Cichlid, Cichlidae

Cichlids is a family of fish and they have been found in various countries in freshwater, tropical and subtropical regions (Jonna). Cichlids have the ability of regenerating their teeth if they were to get injured.

Cichlid tooth replacement can be separated into three stages: initiation, cellular differentiation, and secretion. Tooth replacement is started when successional lamina (SL) is formed from labial epithelial cells and interacts with the dental epithelium ("Cichlid Tooth Regeneration"). The SL continues to develop and interact with mesenchymal cells, which will differentiate and condense into dental papilla in the cellular differentiation phase ("Cichlid Tooth Regeneration"). Bone starts to form after epithelium invagination starts to form a cap tooth with three layers: inner dental epithelium (IDE), outer dental epithelium (ODE), and intermediate layer ("Cichlid Tooth Regeneration"). The mesenchyme and epithelial cells continue to proliferate and differentiate into enameloid-secreting ameloblasts and denine-secreting odontoblastsare, which help to further form the new teeth ("Cichlid Tooth Regeneration"). These secreting particles create the hard tissue of the teeth. Ameloblasts help initiate the breakdown of the gubernacular cord, which allows the old tooth to get pushed out by enameloid secreting cells ("Cichlid Tooth Regeneration"). As the old tooth is getting pushed out the new tooth is building stronger and replacing it until there is a brand new tooth.

Jonna, R. "Cichlidae (Cichlids)." *Animal Diversity Web*. Regents of the University of Michigan, 27 Feb. 2004. Web. 29 Nov. 2014.

http://animaldiversity.org/accounts/Cichlidae/#geographic_range

"Cichlid Tooth Regeneration: Pursing Replaceable Tooth for Human." *Developmental Biology Interactive*. Developmental Biology Interactive, 2014. Web. 29 Nov. 2014. http://www.devbio.biology.gatech.edu/?page_id=8699

29) Rat, Rattus

Rats can be found all over the world and can live for up to 5 years ("Rat"). Rats have the ability of regenerating their liver after partial hepatectomy.

Partial hepatectomy is the surgical removal of the damaged part of the liver. In order for the liver to gain back the mass of tissue that was lost it uses already existing hepatocytes to undergo replication (Michalopoulos). The hepatocytes undergo replication in synch with the circadian rhythm of the animal, which is 24 hours after the operation on the rat's liver (Michalopoulos). There are many signals from the cytokine network that are induced in order for the hepatocytes to replicate and regrow the liver. HGF and EGF receptor ligand family have been found to be important growth factors in initiating and controlling the cell cycle of the hepatocytes (Michalopoulos). The hepatocytes will continue to replicate until the liver has reached its maximum size again and then the cells will go into quiescent stage of the cycle.

"Rat." *Rat (tus Tus)*. Http://a-z-animals.com/, 2013. Web. 1 Dec. 2014. http://a-z-animals.com/animals/rat/

Michalopoulos, George K. "Liver Regeneration after Partial Hepatectomy." *The American Journal of Pathology* 176.1 (2010): 2-13. *NCBI*. Web. 1 Dec. 2014. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2797862/

30) Brown Hydra, Hydra oligactis

Brown Hydra can be found in freshwater in Australia, Europe, and North America (Weinberger). They use stinging tentacles on the top of their head to catch their prey. Brown Hydra has been found to be able to regrow their head and/or foot if it were to get cut or torn off.

Hydras are remarkable in the fact that they have three different kinds of stem cell throughout their entire body that are continuously replicating and differentiating into the appropriate structure. Stem cells can be found in the body column and are able to differentiate into the tissues and structures in the arm (Frank et al.). Interstitial cells, which are multipotent, are found in the spaces throughout the body and differentiate into neurons, gametes, nematocytes, and secretory cells (Frank et al.). If the head and/or foot happens to get cut off the body will undergo morphallactic regeneration, which is where the tissue near the wound site will remold to build the missing structures (Frank et al.). This means that the epithelial cells closest to the wound will stretch to fill in the missing piece. After that the cells in the tissue will dedifferentiate and re-differentiate into the cells needed to produce the head or foot.

Weinberger, Jana D. "Hydra Oligactis." *ADW*. Animal Diversity Web, 7 June 1999. Web. 1 Dec. 2014.
http://animaldiversity.org/accounts/Hydra_oligactis/

Frank, Uri, Thomas Leitz, and Werner A. Muller. "The Hydroid Hydractinia: A Versatile, Informative Cnidarian Representative." *BioEssays* 23.10 (2001): 963-71. *Wiley Online Library*. Web. 1 Dec. 2014. http://onlinelibrary.wiley.com/doi/10.1002/bies.1137/abstract

31) Tropical clawed frog, Xenopus tropicalis

Tropical clawed frogs can be found in West Africa near freshwater sources (IUCN). Tropical clawed frog tadpoles have the remarkable ability of regenerating their tail if it were amputated.

The tadpole's body is still developing into an adult frog up until metamorphosis which gives it an edge in regeneration since a lot of the cells are still in a stem cell- like state. This state allows the cells to be activated by Wnt, Fgf, Bmp, Notch and TGF-beta pathways and differentiate into specific cells (Lin & Slack). After the tail is amputated the body produces reactive oxygen species (ROS) which increase the Wnt and Notch signaling (Love et al.). Muscle cells near the wound site proliferate and form a protective covering over the wound called the stump. The signals activate the spinal cord and notochord cells to proliferate and grow the spinal cord into the stump of the tail. The signals also activate muscle satellite cells and melanophore precursors to generate muscle and melanophores, respectively (Lin & Slack). The surrounding tissue cells continue to proliferate and grow the tail to its maximum size. Once the tail has reached its maximum size the cells will continue to differentiate but they will not grow the tail.

IUCN SSC Amphibian Specialist Group 2014. *Xenopus tropicalis*. The IUCN Red List of Threatened Species. Version 2014.3. Web. 1 Dec. 2014.
http://www.iucnredlist.org/details/58167/0

Lin, Gufa, and Jonathan M.W. Slack. "Requirement for Wnt and FGF Signaling in Xenopus Tadpole Tail Regeneration." *Developmental Biology* 316.2 (2008): 323-35. *Science Direct*. Web. 1 Dec. 2014. http://www.sciencedirect.com/science/article/pii/S0012160608000766

Love, Nick R., Yaoyao Chen, Shoko Ishibashi, Paraskevi Kritsiligkou, Robert Lea, Yvette Koh, Jennifer L. Gallop, Karel Dorey, and Enrique Amaya. "Amputation-induced Reactive Oxygen Species Are Required for Successful Xenopus Tadpole Tail Regeneration." *Nature Cell Biology* 15 (2013): 222-28. *Nature Cell Biology*. Web. 1 Dec. 2014. http://www.nature.com/ncb/journal/v15/n2/full/ncb2659.html

32) Red wiggler, Eisenia fetida

Red wigglers can be found in the entire world where the soil is suitable for them to live in. They are great for compost piles by grinding up the food they swallow in their gizzard (NYC). Red Wigglers have the ability of regenerating full sections of their body if they were to get cut into pieces.

Red wigglers have the ability of regenerating their missing sections through two processes: stem cells and cellular reorganization (Clark). Stem cells become active once there has been an injuring. They start proliferating and then differentiating into the various segments and organs of the worm. The other process, cellular reorganization, is where the tissue closest to the wound undergoes dedifferentiation and then differentiates into the needed tissue (Clark). Although the worm must not lose a lot of the head segments or it will not be able to regenerate.

NYC Department of Sanitation's Bureau of Waste Prevention, Reuse & Recycling. *NYC Compost Project Tip Sheet*. New York City: NYC Department of Sanitation's Bureau of Waste Prevention, Reuse & Recycling, 2013. *NYC Compost Project Tip Sheet*. NYC Department of Sanitation's Bureau of Waste Prevention, Reuse & Recycling, May 2013. Web. 2 Dec. 2014. http://www.nyc.gov/html/nycwasteless/downloads/pdf/materials/tipsheet-worm-facts.pdf

Clark, Patterson. "If an Earthworm Loses Its Head, Will It Grow Another?" *The Washington Post*. The Washington Post, 3 June 2013. Web. 2 Dec. 2014. http://www.washingtonpost.com/wp-srv/special/metro/urban-jungle/pages/130604.html

33) Mammal, Mammalia

Mammals have become the most complex structures in the world, which is good but one thing they lack is major regenerative abilities. One regeneration capability that mammals do have is the ability to regenerate digits after amputation.

The nail is made of the matrix, cuticle, and lunula. Nail stem cells (NSCs) have been found to reside in the matrix of the nail (Takeo et al.). These cells are used to continually regenerate new nails with the help of the Wnt signal pathway. Once the digit has been amputated the NSCs and Wnt signal pathway direct their attention to regenerating the digit. The Wnt signal pathway attracts nerves that help a blastema form filled with mesenchymal cells (Takeo et al.). Once the blastema is formed the cells undergo dedifferentiation and prolific replication. These new cells will differentiation into muscle, tendons, nerves, and other sensory cells to generate the new digit. Once the digit has been fully regenerated the blastema will degenerate and the mesenchymal cells will go back into the quiescent stage of mitosis.

Takeo, Makoto, Wei Chin Chou, Qi Sun, Wendy Lee, Piul Rabbani, Cynthia Loomis, M. Mark Taketo, and Mayumi Ito. "Wnt Activation in Nail Epithelium Couples Nail Growth to Digit Regeneration." *Nature*499.7457 (2013): 228-32. *Nature*. Web. 2 Dec. 2014. http://www.nature.com/nature/journal/v499/n7457/full/nature12214.html

34) North American Opossum, Didelphia virginiana

North American Opossums are found on the North American continent. They are the only pouched mammal found in the United States and Canada ("Opossums"). Neonatal opossums have the ability of regenerating their spinal cord if it was damaged in some way.

Soon after the spinal cord has been damaged signals are sent out to warrant help from the rest of the body. Microglial cells migrate to the wound site and start proliferating. They start to differentiate into structural cells and join together to form the missing spinal cord section. Microglial cells also differentiate into sensory fibers that will join together and reconnect the cord to the motoneurons (Mladinic et al.). The cells also differentiate into cells that will form the axons where the fibers connect the cord to the motoneurons (Mladinic et al.). Finally the microglial cells will differentiate into epithelial cells and form the tissue that surrounds the spinal cord and gives it support. When the spinal cord and neurons have been regenerated the cells will stop proliferating and will migrate away from the previously injured site.

"Opossums." *National Geographic*. National Geographic Society, 2014. Web. 2 Dec. 2014. http://animals.nationalgeographic.com/animals/mammals/opossum/

Mladinic, M., K. J. Muller, and J. G. Nicholls. "Central Nervous System Regeneration: From Leech to Opossum." *The Journal of Physiology* 587.12 (2009): 2775-782. *NCBI*. Web. 2 Dec. 2014. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2718237/#b27

35) Leech, Hirudinea

Leeches can be found all over the world in freshwater sources. They feed on a variety of animal's blood and have been used in medicinal purposes ("Leech Therapy"). Leeches also have the ability of regenerating their central nervous system.

Once the central nervous system has been cut or crushed nitric oxide is produced. Nitric oxide along with glial calcium waves and ATP help attract and move microglial cells toward the injured site (Mladinic et al.). Once the microglial cells are near the injured site and activated they produce laminin, which is a protein that promotes the outgrowth of axons (Mladinic et al.). Along with regenerating the axons the synaptic connections must be fixed in order for the animal to control the newly generated nervous system. This is done by using sensory cells that were not harmed and sending an axon to the neighboring ganglion (Mladinic et al.). Once they are connected there is a direct connection to the motor cell that will produce the movements of the body.

"Leech Therapy." *PBS*. PBS, 2014. Web. 3 Dec. 2014. http://www.pbs.org/wnet/nature/bloodysuckers/leech.html

Mladinic, M., K. J. Muller, and J. G. Nicholls. "Central Nervous System Regeneration: From Leech to Opossum." *The Journal of Physiology* 587.12 (2009): 2775-782. *NCBI*. Web. 2 Dec. 2014. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2718237/#b27

36) Sea cucumbers, Holothuroidea

Sea cucumbers live in all of the oceans, usually on the ocean floor. They can range from 0.75 inches to 6.5 feet and are omnivores ("Sea Cucumbers"). Their unique ability is being able to split in half and create two productive organisms by transverse fission (architomy) and fragmentation.

Transverse fission occurs at specific sites on the body of the sea cucumber. First the connective tissue of the dermis must become elastic enough to split. It is controlled by juxtaligamental cells, which secrete granule-derived substances in response to the nervous system. These molecules use stiparin and tensilin to alter the mutable collagenous tissue (MCT) (Dolmatov). Tensilin can be related to tissue inhibitors of metalloproteinases (TIMPs) (Dolmatov). TIMPs normally block matrix metalloproteinases (MMPs) and develop cross-linked complexes to strengthen the MCT. When tensilin is present MMP destroys the cross-linked complexes allowing MCT to become pliable (Dolmatov). As the wall becomes more pliable it starts to constrict at the specific sites on the body, which increases as the body twists, stretches, and causes muscle contractions. Right before the sea cucumber breaks into two parts the walls fuse together not allowing any of its organs to escape. The anterior fragment has the aquapharyngeal complex (AC), gonads, and one or two segments of the gut. The posterior fragment has the cloaca, larger portion of the gut, and respiratory trees (Dolmatov). In the anterior fragment, the first descending portion of the intestine (1DP) undergoes partial atrophy while the posterior end is repaired. The 1DP grows back as the intestine from dedifferentiated cells and migration of enterocytes from the remaining 1DP (Dolmatov). The cloaca also develops from dedifferentiated cells and allows the intestine to

grow into it to complete the digestive system. The longitudinal muscle bands are formed from coelomic epithelium which covers the muscles (Dolmatov). Respiratory trees also develop from transforming the dorsal wall of the anterior region of the cloaca caused by specializing cells in the luminal epithelium (Dolmatov). The body grows by an outgrowth that appears and dedifferentiates and re-differentiates the cells. In the posterior fragment of the sea cucumber the only major thing to form is the AC and strengthen the wall where it was separated from the other half. The AC is formed from connective tissue swelling and the intestine thinning and growing up the mesentery, while the wall is strengthened in the same way as the anterior end.

"Sea Cucumbers." *National Geographic*. National Geographic Society, 2014. Web. 3 Dec. 2014. http://animals.nationalgeographic.com/animals/invertebrates/sea-cucumber/

Igor Yu. Dolmatov, "Asexual Reproduction in Holothurians," The Scientific World Journal, vol. 2014, Article ID 527234, 13 pages, 2014. Web. 3 Dec. 2014. http://www.hindawi.com/journals/tswj/2014/527234/#B39

37) Chinese Mystery Snail, Bellamya chinensis

Chinese mystery snails can be found in southeast Asia, Japan, eastern Russia, and the United States (Kipp et al.). Chinese mystery snails have the ability of regenerating their eye if they were to get amputated or damaged.

The mystery snail has the ability of regenerating its eye from the mid-eyestalk. Once the eye has been amputated the integumentary epithelium folds back on itself to form a shallow cleft which houses epithelial cells (Bever & Borgens). These epithelial cells undergo transdetermination which switches the progenitor cell to a closely related cell type (Manohar & Lagasse). The newly switched cells then proliferate and differentiate into the various parts of the eye. It has been found that the cells differentiate into the retina and new lens by day 14 of postamputation (Bever & Borgens. The new cells also form the tissues that surround the eye and give it structure. When the eye has regenerated completely the cells will stop proliferating and differentiating.

Kipp, R.M., A.J. Benson, J. Larson, and A. Fusaro. *Cipangopaludina chinensis malleata*. USGS Nonindigenous Aquatic Species Database, Gainesville, FL. 2014. Web. 3 Dec. 2014 http://nas.er.usgs.gov/queries/factsheet.aspx?SpeciesID=1045

Bever, M. M., and R. B. Borgens. "Eye Regeneration in the Mystery Snail." *The Journal of Experimental Zoology* 245.1 (1988): 33-42. *NCBI*. Web. 3 Dec. 2014. http://www.ncbi.nlm.nih.gov/pubmed/3351443

Manohar, Rohan, and Eric Lagasse. "Transdetermination: A New Trend in Cellular Reprogramming." *Molecular Therapy* 17.6 (2009): 936-38. *Nature*. Web. 3 Dec. 2014. http://www.nature.com/mt/journal/v17/n6/full/mt200993a.html

38) Humans, Homo sapiens

In recent years there have scientists researching more about the kidney and its regenerative, or lack there of, abilities. Some scientists have found that the kidney can regenerate damaged portions of itself through cellular repair. Bone marrow-derived cells (BMDC) have been found to migrate to the kidney, proliferate and transdifferentiate into the certain cells needed to repair the kidney (Little). They differentiate into tubular epithelial cells that rebuild the structure of the kidney (Little). Mesangial cells are also produced by the BMDCs and create the smooth tissues around the blood vessels in the kidney (Little). The surrounding good cells have also been shown to contribute to the regenerative process in acute damaged areas by proliferating and increasing the kidney mass. This type of repair allows the kidney to be scar-free and work properly, although if there is chronic injury the damage will turn into scarring and functional loss that cannot be undone.

Little, Melissa H. "Regrow or Repair: Potential Regenerative Therapies for the Kidney." *Journal of the American Society*17.9 (2006): 2390-401. *JASN*. Web. 3 Dec. 2014. http://jasn.asnjournals.org/content/17/9/2390.full

39) Percival's Spiny mouse, Acomys percivali

Percival's Spiny mice are found in Kenya, Somalia, South Sudan, and Uganda (Dieterlen & Schlitter). They are herbivores and live in areas where there is little population so they don't have a lot of predators. Percival's Spiny mice have the ability of regenerating skin, hair follicles, and tissue after it is ripped off through autonomy or damaged.

Soon after the injury hemostasis would stop the wound from bleeding and a scab would form. Epithelial cells would dedifferentiate and migrate to the wound site. After migrating the cells would re-differentiate and use contractions of the skin to continue to heal the wound (Seifert et al.). It was also found that collagen fibrils from the extracellular matrix would create a porous structure (Seifert et al.). This porous structure allowed for a scar-free wound and clear regeneration instead of just healing. The hair follicles of the mouse can also regenerate by using highly prolific epidermal cells and Wnt signaling to form the follicles.

Dieterlen, F. & Schlitter, D. 2008. *Acomys percivali*. The IUCN Red List of Threatened Species. Version 2014.3. Web. 3 Dec. 2014. http://www.iucnredlist.org/details/272/0

Seifert, Ashley W., Stephen G. Kiama, Megan G. Seifert, Jacob R. Goheen, Todd M. Palmer, and Malcolm Maden. "Skin Shedding and Tissue Regeneration in African Spiny Mice (Acomys)." *Nature* 489.7417 (2012): 561-65. *NCBI*. Web. 3 Dec. 2014. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3480082/

40) Purple sea urchin, Paracentrotus lividus

Purple sea urchins can be found on the western coast of Ireland (). Sea urchin embryos have the ability of regenerating their cilia if they happened to be deciliated.

Sea urchins have a large pool of pre-existing ciliary tubulin and dynein proteins in the embryo which are the building blocks for cilia (Stephens, p. 311-29). After deciliation the proteins enhance in synthesis to provide enough building blocks for the cilia to regenerate. The proteins are moved along an axonemal microtubule to the distal tip by Hsp70 and Hsp40 cognate signals (Casano et al.). Once ciliary tubulin and dynein proteins are at the distal tip they undergo incorporation to form a membrane. Further production of the proteins will elongate the cilia until it reaches its maximum size at which point the proteins will stop being overly synthesized.

Stephens, R. E. "Differential Protein Synthesis and Utilization during Cilia Formation in Sea Urchin Embryos."*Developmental Biology* 61.2 (1977): 311-29. *ScienceDirect*. Web. 3 Dec. 2014.
http://www.sciencedirect.com/science/article/pii/0012160677903013

Stephens, R. E. "Tubulin and Tektin in Sea Urchin Embryonic Cilia: Pathways of Protein Incorporation during Turnover and Regeneration." *Journal of Cell Science* 107 (1994): 683-92. *Journal of Cell Science*. Web. 4 Dec. 2014.
http://jcs.biologists.org/content/107/2/683.full.pdf

Casano, Caterina, Fabrizio Gianguzza, Maria C. Roccheri, Rossana Di Giorgi, Luigia Maenza, and Maria A. Ragusa. "Hsp40 Is Involved in Cilia Regeneration in Sea Urchin Embryos." *Journal of Histochemistry & Cytochemistry*51.12 (2003): 1581-587. *Sage Journals*. Web. 4 Dec. 2014. http://jhc.sagepub.com/content/51/12/1581.full

41) Noble Feather Star, Comanthina nobilis

Noble Feather Stars can be found in the Indo-Pacific region ("Noble Feather Star"). During the day they are curled up into a ball anchored to the ocean floor, but at night they extend their arms to catch food. Noble Feather Stars have the unique ability of regenerating their arm if it is cut off or pulled off.

Soon after the arm is amputated a blastema forms at the regenerating tip. The blastema is made of proliferating mesenchyme cells that were originally unspecialized amoebocytes (Kondo & Akasaka). Amoebocytes originated from the satellite cells of the cortex of the brachial nerve and differentiate into the cicatrical tissue which creates the stump of where the arm will grow (Kondo & Akasaka). The mesenchyme cells differentiate into chondrocytes that are used to form the cartilage of the arm. Coelomocytes are produced from the coelothelium and proliferate to regenerate the coelomic system of the Feather Star from the stump. The coelomic canals continue to provide the necessary cells to further the coelomic system and regenerate the coelomic cord (Kondo & Akasaka). Nerve cells can also be seen differentiating and becoming neurosecretory-like cells and axonal processes which allow the nerves to relay signals. Myocytes finally start to surround the nerves and differentiate into the different muscular tissues. Once the arm has been fully regenerated the cells will go back into the quiescent stage of the cell cycle.

"Noble Feather Star, Comaster Nobilis." RedOrbit- *Echinoderms Reference Library*. RedOrbit, 2014. Web. 4 Nov. 2014.

http://www.redorbit.com/education/reference_library/animal_kingdom/echinoderms/1112850697/noble-feather-star-comaster-nobilis/

Kondo, M., and K. Akasaka. "Regeneration in Crinoids." *Developmental, Growth, and Differentiation* 52.1 (2010): 57-68.*NCBI*. Web. 4 Dec. 2014. http://www.ncbi.nlm.nih.gov/pubmed/20078653

42) Antarctic brittle star, Ophionotus victoriae

Antarctic brittle stars can be found around the continent of Antarctica (Fratt & Dearborn). They are known to have 5 arms that they use to walk around on and catch its prey with. Antarctic brittle stars have the ability of regenerating a lost or damaged arm.

Shortly after the arm is damaged or amputated a blastema is formed over the wound comprised of stem cells that migrated to the wound. The stem cells undergo prolific replication and gene expression is activated. The genes help differentiate the newly replicated cells into structural proteins and segmentation (Burns et al.). The cells will become the new tissue, muscle, and organs in the newly formed arm. The genes also control the energy needed to regenerate the arm and controlling the stem cells so that once the arm is completely regenerated they stop replicating (Burns et al.). The genes are thought be controlled by Wnt/beta-catenin pathway and TGF beta signaling pathways (Burns et al.). The overall regeneration process starts immediately after the injury but due to the extremely cold waters the animal delays the onset of regeneration of around 5 months (Burns et al.).

Fratt, and Dearborn. "Ophionotus Victoriae Bell, 1902." *Ophionotus Victoriae*. Antarctic Field Guide, 1984. Web. 4 Dec. 2014. http://afg.biodiversity.aq/species/89-ophionotus-victoriae

Burns, G., M. C. Thorndyke, and M. S. Clark. "Transcriptome Pyrosequencing of the Antarctic Brittle Star Ophionotus Victoriae." *Marine Genomics* 9 (2013): 9-15. *NCBI*. Web. 4 Dec. 2014.

http://www.ncbi.nlm.nih.gov/pubmed/23904059

43) Sea Star, Asteriidae gray

Asteriidae gray can be found in every ocean on Earth. Asteriidae gray is a family of the sea stars and they are able to regenerate their pyloric caeca. The pyloric caeca is an organ that helps in the digestion, absorption and storage of food that is passed from the stomach (Anderson, p. 47-61).

Once the pyloric caeca is damaged in the arm undifferentiated cells will migrate to the central stump to regenerate the caeca in the arm. The cells begin to replicate and then differentiate into the cells needed to make the caeca. These cells are led through mesenteric tunnels and divide in half to give rise to two tubes (Anderson, p. 1-23). The cells also differentiate into secretory cells and gland cells that line the roof and floor of the duct to produce secretions and currents, respectively, as the caeca is grown (Anderson, p. 1-23). Once the caecum is fully regenerated the cells will stop proliferating and disperse to other parts of the body.

Anderson, John Maxwell. "STRUCTURE AND FUNCTION IN THE PYLORIC CAECA OF ASTERIAS FORBESI." *The Biological Bulletin* 105.1 (1953): 47-61. *The Biological Bulletin*. Web. 7 Dec. 2014. http://www.biolbull.org/content/105/1/47.abstract

Anderson, John Maxwell. "STUDIES ON VISCERAL REGENERATION IN SEA-STARS. II. REGENERATION OF PYLORIC CAECA IN ASTERIIDAE, WITH NOTES ON THE SOURCE OF CELLS IN REGENERATING ORGANS1." *The Biological Bulletin* 128.1 (1965): 1-23. *The Biological Bulletin*. Web. 7 Dec. 2014.

http://www.biolbull.org/content/128/1/1.abstract

44) Eastern (Red-spotted) newt, Notophthalmus viridescens

Eastern newts are commonly found on the eastern side of the United States near water sources or damp forests ("Eastern/Red-spotted Newt"). These salamanders are nocturnal which means that their eyesight is very important to them. Eastern newts have the ability of regenerating their eye lens if it was to get damaged so they can continue to use their eyes.

Once the lens has been damaged the iris epithelial cells (IECs) under depigmentation and dedifferentiation (Wassmer et al.). These cells proliferate near the mid-dorsal margin of the iris epithelium and differentiate into the lens vesicle. As the cells continue to proliferate they are added to the outer portion of the lens vesicle which helps the lens vesicle expand. While this is happening lens fibers are elongating and differentiating in the inner posterior layer of the vesicle (Wassmer et al.). Next protein is signaled to form as crystalline in the lens and the lens fibers differentiate into primary and secondary layers of the lens (Wassmer et al.). To finish it off, the IECs differentiate into the lens capsule and the lens detaches from the iris (Wassmer et al.). Once the lens has been regenerated the cells will stop proliferating and differentiating into the various pieces of the lens.

"Eastern/Red-spotted Newt." *Eastern Red-spotted Newt*. New Hampshire Fish and Game, 2014. Web. 7 Dec. 2014. http://www.wildlife.state.nh.us/Wildlife/Nongame/salamanders/east-redspot_newt.htm

Wassmer, Sarah, Margaret Beddaoui, Payman Rajai, Rejean Munger, and Catherine Tsilfidis. "A Focus on the Optical Properties of the Regenerated Newt Lens." *PLoS ONE* 8.8 (2013): E70845. *PLoS ONE*. Web. 7 Dec. 2014. http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0070845

45) Hermann’s tortoise, Testudo hermanni

Hermann’s tortoise can be found near the Italian Peninsula (van Dijk et al.). It lives in evergreen oak forests and is not aquatic. Hermann’s tortoise has the ability of regenerating its scutes on the shell to allow the tortoise to grow and to heal injured sections.

The tortoise is only able to regenerate the scutes during the spring season so if they get injured before that time period they must learn to survive with the injury. Although during the winter season alpha-keratin cells are produced in the soft epidermis (Alibardi). Once spring comes cell proliferation is activated around the hinge and tips of the marginal scutes to produce beta-keratin cells (Alibardi). The beta-keratin cells create a thick corneous growing ring layer and a homogenous layer along the scute surface (Alibardi). Once the layer is formed the old scute is able to slough off and reveal the newly formed scute.

van Dijk, P.P., Corti, C., Mellado, V.P. & Cheylan, M. 2004. *Testudo hermanni*. The IUCN Red List of Threatened Species. Version 2014.3. Web. 7 Dec. 2014. http://www.iucnredlist.org/details/21648/0

Alibardi, L. "Proliferation in the Epidermis of Chelonians and Growth of the Horny Scutes." *Journal of Morphology*265.1 (2005): 52-69. *NCBI*. Web. 7 Dec. 2014. http://www.ncbi.nlm.nih.gov/pubmed/15880409

46) Human, Homo sapiens

Glomerulosclerosis occurs when the podocytes that surround the glomerulus in the kidney are depleted (NIH). The podocytes help the kidney filter the toxins out of the body and keep the protein and other things the body can use in the body (Pavenstadt et al.). In order for the body to filter out the toxins and heal the kidneys the podocytes must be regenerated and researches have found cells in the body that have the potential to do that. There are progenitor cells in the Bowman's capsule called CD133+CD24+ that can proliferate and differentiate into the podocytes (Pavenstadt et al.). The more progenitor cells that are produced the more podocytes can be produced and help the kidney return to its proper filtering state.

NIH. "Glomerular Diseases." *Glomerular Diseases- National Kidney and Urologic Diseases Information Clearinghouse (NKUDIC)*. NIH Publication, Feb. 2014. Web. 7 Dec. 2014. http://kidney.niddk.nih.gov/KUDiseases/pubs/glomerular/index.aspx

Pavenstadt, Hermann, Wilhelm Kriz, and Matthias Kretzler. "Cell Biology of the Glomerular Podocyte." *Physiological Reviews* 83.1 (2003): 253-307. *Physiological Reviews*. Web. 9 Dec. 2014. http://physrev.physiology.org/content/83/1/253

47) Old world rat or mice, Murinae

Old world rat or mice can be found on every continent besides Antarctica. They have the ability of regenerating the hairs in their ear after damage.

Cochlear hair in the ear is important for hearing and balance. If the hair were to get damaged the individual or animal could loose some of their hearing or all of it and impair their sense of balance. In the cochlea there is a sensory epithelium that houses Lgr5-expressing cells that can be differentiated into hair cells to regenerate the hairs (Shi et al.). After damage Wnt signals have been found to become initiated and signal Lgr5-positive cells to proliferate and form neurospheres that differentiate into hair cells (Shi et al.). Once the hairs have been regenerated the Wnt signals cease and Lgr-5 expressing cells stop proliferating.

Shi, F., J. S. Kempfle, and A. S. Edge. "Wnt-responsive Lgr5-expressing Stem Cells Are Hair Cell Progenitors in the Cochlea." *The Journal of Neuroscience* 32.28 (2012): 9639-648. *NCBI*. Web. 7 Dec. 2014.
http://www.ncbi.nlm.nih.gov/pubmed/22787049

48) Zebrafish, Danio rerio

Zebrafish can be found in the tropical fresh waters of northern India, northern Pakistan, Nepal, and South Asia. They can grow up to 4-5 centimeters in length and get their name from stripes on their body (Hamel & Mercier). Zebrafish can regenerate their retinal neurons if damaged so they can convey the information they perceive through their eyes to the brain.

After the retina has been damaged Muller glia cells dedifferentiate and proliferate. These cells produce neuronal progenitor cells that proliferate and migrate to the damaged portion of the retina (Gorsuch & Hyde). Once there the progenitor cells differentiate into the various neuronal cells to fill in the damaged portion of the retina. The corepressors Tgif1 and Six3b regulate TGFbeta signaling and the signals are critical to help induce proliferation of photoreceptors (Lenowski et al.). Once the retina has been regenerated the Muller glia cells will stop dedifferentiating and go back into the quiescent stage of mitosis until needed later.

Hamel, J.-F. & Mercier, A. 2013. *Apostichopus japonicus*. The IUCN Red List of Threatened Species. Version 2014.3. Web. 7 Dec. 2014.
http://www.iucnredlist.org/details/180424/0

Gorsuch, R. A., and D. R. Hyde. "Regulation of Müller Glial Dependent Neuronal Regeneration in the Damaged Adult Zebrafish Retina." *Experimental Eye Research* 123 (2014): 131-40. *NCBI*. Web. 7 Dec. 2014.
http://www.ncbi.nlm.nih.gov/pubmed/23880528

Lenkowski, J. R., Z. Qin, C. J. Sifuentes, R. Thummel, C. M. Soto, C. B. Moens, and P. A. Raymond. "Retinal Regeneration in Adult Zebrafish Requires Regulation of TGFβ Signaling." *Glia.* 61.10 (2013): 1687-697. *NCBI*. Web. 7 Dec. 2014. http://www.ncbi.nlm.nih.gov/pubmed/23918319

49) Pacific blood star, Henricia Leviuscula

Pacific blood stars are found in the Pacific Ocean close to where sponges live since they are its prey (Cowles). Pacific blood stars are known to be able to regenerate the pyloric caeca found in their arms after getting injured.

Shortly after the arm is injured a blastema covers the stump made of undifferentiated cells. Near the base of the arm cells begin to re-differentiate to continue the caeca from the central stump into the arm (Anderson, p. 321-42). As more cells are replicated they begin to re-differentiate to continue the caeca, although the cells only differentiate closer to the stump. The cells closest to the tip are still proliferating to give rise to more cells that will make the rest of the arm. The cells also differentiate into the epithelium, which covers the organs in the arm and houses the mucous gland and zymogen cells (Anderson, p. 321-42). The muscle and connective tissue are found to differentiate in the later stages of regeneration. The Tiedemann's pouch forms from specializations in the floor of the tubular caecal regenerate (Anderson, p. 321-42).

Cowles, Dave. "Henricia Leviuscula." *Henricia Leviuscula*. Walla Walla University, 2005. Web. 7 Dec. 2014. http://www.wallawalla.edu/academics/departments/biology/rosario/inverts/Echinodermata/Class%20Asteroidea/Henricia_leviuscula.html

Anderson, John Maxwell. "STUDIES ON VISCERAL REGENERATION IN SEA-STARS. I. REGENERATION OF PYLORIC CAECA IN HENRICIA LEVIUSCULA (STIMPSON)." *The Biological Bulletin* 122.3 (1962): 321-42. *The Biological Bulletin*. Web. 7 Dec. 2014. http://www.biolbull.org/content/122/3/321.abstract

50) Holothuroid sea cucumber, Eupentacta fraudatrix

Holothuroid sea cucumbers can be found in the North Pacific Ocean (Smirnov). They are able eviscerate their organs through the anterior end of the body and then regenerate all of the missing parts.

During evisceration the AC, part of the gonad tubules, and the entire digestive system is lost besides the cloaca (Lamash & Dolmatov). To regenerate the missing body parts it starts by forming a thrombus at the anterior end where the injury is at which prevents major blood loss. The extracellular matrix then begins to migrate and replace the clot and epithelial cells help create a connective tissue which will form the aqyapharyngeal complex (AC) (Lamash & Dolmatov). Next cells start to travel down the torn mesentery expanding the AC which helps create the gut. Mesodermal cells also begin to transdifferentiate into cells that form the intestinal lining (Lamash & Dolmatov). Cells are still proliferating and forming the AC, intestinal ling, and gut all throughout the regeneration process. Once the anterior and posterior primordial unite, the entire gut has formed which means the cells can stop proliferating and differentiating and the animal can start feeding again.

Smirnov, A. "Eupentacta Fraudatrix." *Search NMNH Collections*. Smithsonian National Museum of Natural History, 2014. Web. 7 Dec. 2014. http://collections.mnh.si.edu/search/iz/?qn=Eupentacta+fraudatrix

Lamash NE, Dolmatov IY (2013) Proteases from the Regenerating Gut of the Holothurian *Eupentacta fraudatrix*. PLoS ONE 8(3): e58433. Web. 7 Dec. 2014. http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0058433

51) Freshwater pearl mussel, Margaritifera margaritifera

Freshwater pearl mussels can be found in Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Ireland, Latvia, Luxembourg, Norway, Poland, Portugal, Russia, Spain, Sweden, and the United Kingdom (Molluscs Specialis Group 1996). They are currently marked as endangered. Freshwater pearl mussels have the ability of regenerating shell layers.

The mantle resides under the shell and protects the soft part of the body. It has calciferous cells that proliferate and create calcium carbonate rings around the shell's rim which are called umbos (Nordsieck). As more cells are added to the rim near the mantle they start to move up the shell in a cohesive manner creating a hard protective layer. You can tell how old a mussel is by looking at how many layers it has like a tree. Objects can also be caught in between the mantle and the shell and get covered with the aragonite, calcium carbonate mixture to create a pearl (Nordsieck).

Mollusc Specialist Group 1996. *Margaritifera margaritifera*. The IUCN Red List of Threatened Species. Version 2014.3. Web. 7 Dec. 2014.
http://www.iucnredlist.org/details/12799/0

Nordsieck, Robert. "Mussels and Clams (Bivalvia)." *Mussels and Clams (Bivalvia)*. The Living World of Molluscs, 2014. Web. 7 Dec. 2014.
http://www.molluscs.at/bivalvia/index.html?/bivalvia/main.html

52) Rabbits, Lepus curpaeums

Rabbits can be found on every continent besides Antarctica (Bradford). They have large ears which are great at capturing sound waves and allowing the rabbit to have great hearing. Rabbits have the ability of regenerating tissue after having a hole punched in their ear which allows them to keep their great hearing.

Soon after a hole is punched in a rabbits ear a blastema forms around the edges of the hole. The epidermal cells proliferate and create downgrowths which grow into the intact dermis of the original skin (Goss & Grimes). The epidermal cells then proliferate more and differentiate into cartilage tissue sheets as it is moved across the hole (Goss & Grimes). Once the hole has been completely sealed the epidermal cells stop proliferating and the blastema disintegrates. This healing process creates a scar-free ear compared to other animals that can't produce a blastema and get scars.

Bradford, Alina. "Rabbits: Habits, Diet & Other Facts." *LiveScience*. TechMedia Network, 05 June 2014. Web. 7 Dec. 2014. http://www.livescience.com/28162-rabbits.html

Goss, R. J., and L. N. Grimes. "Epidermal Downgrowths in Regenerating Rabbit Ear Holes." *Journal of Morphology*146.4 (1975): 533-42. *NCBI*. Web. 7 Dec. 2014. http://www.ncbi.nlm.nih.gov/pubmed/1171254

53) Killer whale, Orcinus orca

Killer whales inhabit every ocean in the world. To keep their bodies warm in the freezing waters they have a layer of blubber underneath the dermis that can be as thick as 3-4 inches (Sea World). Killer whales have the ability of regenerating their skin.

After being in the freezing Antarctic waters algal growth can accumulate on the outer skin of the whales giving it a yellowish tinge. To be able to slough off the old skin and rid itself of the algal growth the Killer whale migrates to warmer waters. Scientists also believe that the whales go to warmer water so that they won't freeze while putting a tremendous amount of energy/heat into the skin regeneration and sloughing and not in staying warm. Once they reach the warmer waters the blood supply can be pushed to the outer surfaces of the body which will help cells in the epidermis proliferate ("Belluga Whale Fact Sheet"). As they proliferate they add layers of epithelial cells under the current layers pushing the top cells to elongate and cornify. Once they are cornified the cells and algal growth can be sloughed off by using rocks or some other hard surface.

Sea World. "Killer Whales." *KILLER WHALES (Orcinus Orca) - Physical Characteristics*. Sea World Parks & Entertainment, 2014. Web. 7 Dec. 2014. http://seaworld.org/animal-info/animal-infobooks/killer-whale/physical-characteristics/

"Belluga Whale Fact Sheet." *Alliance of Marine Mammal Parks and Aquariums*. Alliance of Marine Mammal Parks and Aquariums, 2014. Web. 7 Dec. 2014.

http://www.ammpa.org/doc_beluga_factsheet.html

54) Long-spined sea urchin, Diadema antillarum

Long-spined sea urchins can be found all over the Caribbean. They have spines that can grow up to 20 cm (Kluijver et al.). The Long-spined sea urchin has the ability of regenerating its spines after they have damaged.

After the spines are damaged conical micro-spines are formed by specialized cells that deposit calcite crystal (Politi et al.). The micro-spines fuse together to form an inner stereom. This inner stereom is structurally supported by the addition of more specialized cells that deposit amorphous calcium carbonate (ACC) along the outside of the stereom (Politi et al.). The spine gradually gets thicker and grows longer as more ACC is deposited. The skeleton-forming cells are proliferating during this process but do not migrate up the stereom until the spines have thickened completely (Gorzelak et al.). Once the skeleton has been formed the entire cells stop proliferating and migrating.

Kluijver, M. De, G. Gijswijt, R. De Leon, and I. Da Cunda. "Long-Spined Urchin." *Marine Species Identification Portal : Long-spined Urchin - Diadema Antillarum*. Key of Nature, 2014. Web. 7 Dec. 2014. http://species-identification.org/species.php?species_group=caribbean_diving_guide&id=380

Politi, Yael, Rebecca A. Metzler, Mike Abrecht, Benjamin Gilbert, Fred H. Wilt, Irit Sagi, Lia Addadi, Steve Weiner, and P. U.P.A Gilbert. "Transformation Mechanism of Amorphous Calcium Carbonate into Calcite in the Sea Urchin Larval Spicule." *Proceedings of the National*

*Academy of Sciences of the United States of America*105.45 (2008): 17362-7366. *PNAS*. Web. 7 Dec. 2014.

http://www.pnas.org/content/105/45/17362.full

Gorzelak, P., J. Stolarski, P. Dubois, C. Kopp, and A. Meibom. "^{26}Mg Labeling of the Sea Urchin Regenerating Spine: Insights into Echinoderm Biomineralization Process." *Journal of Structural Biology* 176.1 (2011): 119-26. *NCBI*. Web. 7 Dec. 2014.

http://www.ncbi.nlm.nih.gov/pubmed/21803159

55) Zebrafish, Danio rerio

Zebrafish can be found in the tropical fresh waters of northern India, northern Pakistan, Nepal, and South Asia. They can grow up to 4-5 centimeters in length and get their name from stripes on their body (Hamel & Mercier). If their fin was to get injured or cut off they have the ability of regenerating it.

Zebrafish have rays of dermal bone lined with osteoblasts and comprised of fibroblasts, which helps in the fast regrow and recovery. Within hours of the fin being amputated the epidermis covers the wound site and a blastema forms within a day or two. The blastema houses fibroblasts, osteoblasts and dedifferentiated cells. RA, Fgf, and canonical Wnt signaling is used to maintain and proliferate the blastema to allow for further differentiation of cells (Gemberling et al.). The fibroblasts are proliferated to form the structure of tissues in the fin.

Hamel, J.-F. & Mercier, A. 2013. *Apostichopus japonicus*. The IUCN Red List of Threatened Species. Version 2014.3. Web. 7 Dec. 2014. http://www.iucnredlist.org/details/180424/0

Gemberling, Matthew, Travis J. Bailey, David R. Hyde, and Kenneth D. Poss. "The Zebrafish as a Model for Complex Tissue Regeneration." *Trends in Genetics* 29.11 (2013): 611-20. *ScienceDirect*. Web. 7 Dec. 2014. www.sciencedirect.com/science/article/pii/S0168952513001133

56) Japanese sea lily, Metacrinus rotundus

Japanese sea lilies can be found off the west coast of Japan (Hunter). The crown of the sea lily is comprised of arms and pinnules that are used to acquire food. Sea lilies have the capacity to regenerate their crown if it was to get amputated or damaged.

After the crown of the sea lily is amputated a small depression is left on the top of the plate which is quickly covered by a blastema (Amemiya & Oji)). The blastema is made of mesenchyme cells that came from unspecialized amoebocytes. Amoebocytes came from the brachial nerve and give rise to the stumps that the arms will grow out of. The stumps regenerate the arms and pinnules from mesenchyme cells that differentiated into chondrocytes (Amemiya & Oji). The chondrocytes proliferate and form the cartilage of the arms and pinnules. Mesenchyme cells also proliferate and differentiate into coelomocytes that form the coelomic system in the arms and pinnules of the sea lily. The coelomic canals are able to continue to proliferate and provide enough cells to regenerate the entire coelomic system in the sea lily crown (Kondo & Akasaka). Nerve cells also differentiate into the neurosecretory-like cells and axonal processes which help relay siganls. Finally myocytes surround the nerves and differentiate into the different muscular tissues. Once the arms and pinnules are fully formed the blastema is disintegrated and the cells stop proliferating to differentiate.

Hunter, Aaron. "Metacrinus Rotundus (Japanese Sea Lily)." *Metacrinus Rotundus (Japanese Sea Lily)*. Natural History Museum, 2014. Web. 7 Dec. 2014. http://www.nhm.ac.uk/nature-online/species-of-the-day/evolution/metacrinus-rotundus/

Amemiya, Shonan, and Tatsuo Oji. "Regeneration in Sea Lilies." *Nature* 357.6379 (1992): 546-47. *ProQuest*. Web. 7 Dec. 2014. http://0-search.proquest.com.library.uark.edu/docview/204446446?accountid=8361

Kondo, M., and K. Akasaka. "Regeneration in Crinoids." *Development, Growth, and Differentiation* 52.1 (2010): 57-68. *NCBI*. Web. 7 Dec. 2014. http://www.ncbi.nlm.nih.gov/pubmed/20078653

57) Human, Homo sapiens

Humans have the ability of regenerating their skin and shedding it every single day. Our skin is made up of three layers: epidermis, dermis, and subcutis. The epidermis is the outer layer of skin and is made up of several layers of cells called keratinocytes. Keratinocytes are produced form epidermal stem cells and proliferated in the basal layer of the epithelium (Maggioni & Barrandon). As more layers of cells are added beneath the previous layers, the top layers differentiate more by flattening, elongating, and becoming cornified (Eckert et al.). Once this happens they are able to get released from the skin by sloughing, brushing, or washing off.

Maggioni, Melissa, and Yann Barrandon. "Skin Stem Cells: Where Do They Live and What Can They Do?"*EuroStemCell*. EuroStemCell, 9 Feb. 2011. Web. 7 Dec. 2014. http://www.eurostemcell.org/factsheet/skin-stem-cells-where-do-they-live-and-what-can-they-do

Eckert, Richard L., Tatiana Efimova, Shervin R. Dashti, Sivaprakasam Balasubramanian, Anne Deucher, James F. Crish, Michael Sturniolo, and Frederic Bone. "Keratinocyte Survival, Differentiation, and Death: Many Roads Lead to Mitogen-Activated Protein Kinase." *Journal of Investigative Dermatology* 7 (2002): 36-40.*Nature*. Web. 7 Dec. 2014. http://www.nature.com/jidsp/journal/v7/n1/full/5640072a.html

58) Human, Homo sapiens

Humans have the ability of healing a broken bone through a regenerative process. After the bone is broken undifferentiated mesenchymal cells will migrate to the injured site by signals such as beta-catenin and canonical signaling (Chen et al.). Once at the injured site the cells will proliferate and start differentiating into specialized cells. Intramembranous ossification uses the mesenchymal cells and osteoprogenitor cells to create a hard callus formation which will in turn will create the bone (Chen et al.). Endochondral ossification is also taking place which uses mesenchymal cells that differentiate into chrondrocytes. Chrondrocytes produce a cartilaginous matrix which will later calcify and is replaced by bone (Chen et al.). The cells will continue to proliferate and turn into calciferous material until the bone has regained its original size and shape. After the bone has healed the cells will stop proliferating and disperse away from the previously injured site.

Chen, Yan, Heather C. Whetstone, Alvin C. Lin, Puviindran Nadesan, Qingxia Wei, Raymond Poon, and Benjamin A. Alman. "Beta-Catenin Signaling Plays a Disparate Role in Different Phases of Fracture Repair: Implications for Therapy to Improve Bone Healing." *PLoSONE* 4.7 (2007): E249. *NCBI*. Web. 7 Dec. 2014. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1950214/

59) Cattle, Bos Taurus

Soon after the cow gives birth to a calf it will undergo a period called puerperium. This is the period in which the reproductive tissue is repaired and the ovaries function returns. After parturition oxytocin is still being produced to cause the myometrium to contract further. These contractions help discharge the placenta from the uterus, compress uterine vasculature to prevent hemorrhage, and help reduce the uterine size (Senger, p. 315-323). Next the uterus undergoes atrophy of its cells to decrease in size. Finally the maternal caruncles and epithelium are repaired. The maternal caruncles undergo vasoconstriction which causes necrosis of the tissue and sloughing of the mass (Senger, p. 315-323). The mass of caruncle is then repaired through differentiation of epithelial cells to create an endometrial epithelium layer over the caruncle (Senger, p. 315-323). The epithelium where the caruncle detached from undergoes repair as well by proliferating epithelial cells and creating a new epithelium.

Senger, P. L. *Pathways to Pregnancy & Parturition*. 3rd ed. Redmond: Current Conceptions, 2012. Print.

60) Senegal (gray) bichir, Polypterus senegalus

Polypterus senegalus are found in Africa (Morin). These fish use pectoral fins to move around on land as well as swim in water. Polypertus have the ability of regenerating their complex pectoral lobed fins so they can survive on land and in the water.

Once the fin has been amputated a blastema forms over the wounded site by the epithelial basal stratum protruding and folding toward the dorsal side (Cuervo et al.). This structure will expand and create the endoskeleton and dermal skeleton. Sonic hedgehog signaling is induced in the posterior mesenchyme to help migrate the mesenchymal cells to the blastema. Once in the blastema the cells will dedifferentiate and proliferate. The new cells will begin differentiating into chondroblats that, along with the extracellular matrix, will form the new cartilage (Cuervo et al.). To regenerate the endoskeleton cartilage is packed together to form a plate that will help differentiate more cells into long bones and radials form by the perforation and splitting of the plate (Cuervo et al.). As the limbs develop the epithelial cells in the stratum are proliferating and expanding the epithelium. Once the fin has regenerated to its maximum size the cells will stop proliferating and differentiating and the blastema will disintegrate.

Morin, Antoine. "Polypterus." *Polypterus*. The Standen Lab, 2014. Web. 7 Dec. 2014. http://www.standenlab.com/research/projects/polypterus/

Cuervo, Rodrigo, Rocio Hernandez-Martinez, Jesus Chimal-Monroy, Horacio Merchant-Larios, and Luis Covarrubias. "Full Regeneration of the Tribasal Polypterus Fin." *Proceedings of the*

National Academy of Sciences of the United States of America 109.10 (2012): 3838-843. *NCBI*. Web. 7 Dec. 2014. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3309738/

61) Hair regrowth

Hair is comprised of two major structures: follicle and shaft. The follicle is a tunnel-like segment that extends into the dermis (“Hair Loss: The Science of Hair”). The papilla is found at the base of the follicle and contains capillaries to nourish the cells used to create the hair. The bulb surrounds the papilla and is where the cells are proliferating to create the hair shaft and push it out of the epidermis during the anagen phase. Inner and outer sheaths surround the hair shaft, which are used to protect and form the hair shaft. The hair shaft is made of keratin in three layers: medulla, cortex, and cuticle. The medulla is the inner layer, cortex is the second layer, and the cuticle is the outer layer. The cortex and medulla hold the hair’s pigment to give it color (“Hair Loss: The Science of Hair”).

"Hair Loss: The Science of Hair." *Science of Hair: Hair Growth*. WebMD, 1 Mar. 2010. Web. 7 Dec. 2014. http://www.webmd.com/skin-problems-and-treatments/hair-loss/science-hair?page=2

62) European lesser spotted dogfish, Scyliorhinus caniculus

European lesser spotted dogfish can be found in the Northeast Atlantic and Mediterranean Sea (Ellis et al.). The European lesser spotted dogfish has the ability of regenerating parts of its kidney if it were damaged.

After partial nephrectomy, nephrogenesis is induced to regenerate the missing portion of the kidney. It has been that the European lesser spotted dogfish has a nephrogenic zone attached to its kidney. This zone contains mesenchymal cells and prospective tubular cells that are able to proliferate (Elger et al.). The mesenchymal cells would migrate and form tight junctions with one another to create a basement membrane (Elger et al.). Next the prospective tubular cells would migrate and join together to form elongated cysts that could bend and create tubular loops (Elger et al.). The gap at the end of the tube would close up from mesenchymal cells that had differentiated into epithelial cells and become the glomerular epithelial primordial (Elger et al.). After the gap was closed undifferentiated mesenchymal cells would attach to the prospective Boman's capsule and segments of the tubes would differentiate into nephron segments (Elger et al.). The cells would continue to proliferate and add onto the tubes to increase the kidney mass until it was at its maximum size. Once it was big enough the mesenchymal and tubular cells would stop proliferating and differentiating into the different parts of the kidney.

Ellis, J., Mancusi, C., Serena, F., Haka, F., Guallart, J., Ungaro, N., Coelho, R., Schembri, T. & MacKenzie, K. 2009. *Scyliorhinus canicula*. The IUCN Red List of Threatened Species. Version 2014.3. Web. 7 Dec. 2014.

http://www.iucnredlist.org/details/161399/0

Elger, Marlies, Hartmut Hentschel, Jennifer Litteral, Maren Wellner, Torsten Kirsch, Friedrich C. Luft, and Hermann Haller. "Nephrogenesis Is Induced by Partial Nephrectomy in the Elasmobranch Leucoraja Erinacea." *Journal of the American Society of Nephrology* 14.6 (2003): 1506-518. *JASN*. Web. 7 Dec. 2014. http://jasn.asnjournals.org/content/14/6/1506.short

63) Rat, Rattus

Rats can be found all over the world and can live for up to 5 years (“Rat”). Rats have the ability of regenerating amputated limb buds while still in the embryo.

When babies are initially starting to grow in the embryo all of the cells are multipotent. Multipotent means that the cells can differentiate into any type of cell and create any structure of the body. If a limb happens to get amputated while the baby is still developing in the embryo the limb can be regenerated. A blastema-like structure forms over the wound site which house ectodermal and mesenchyme cells (Deuchar). The ectodermal cells proliferate and differentiate to form an intact ectodermal epithelium which covers the wound site (Deuchar). The mesenchyme cells also proliferate and form the bud where the limb will continue to grow out of.

"Rat." *Rat (tus Tus)*. Http://a-z-animals.com/, 2013. Web. 7 Dec. 2014. http://a-z-animals.com/animals/rat/

Deuchar, Elizabeth M. "Regeneration of Amputated Limb-buds in Early Rat Embryos." *Journal of Embryology and Experimental Morphology* 35.2 (1976): 345-54. *Development*. Web. 7 Dec. 2014. http://dev.biologists.org/content/35/2/345.full.pdf

64) Chicken, Gallus gallus domesticus

Chickens can be found all over the world and are used for their meat and eggs. Chickens have the ability of regenerating the hair in their ear if it was damaged.

Cochlear hair in the ear is important for hearing and balance. If the hair were to get damaged the individual or animal could loose some of their hearing or all of it and impair their sense of balance. Supporting cells have been found in the inner ear and are activated by Notch signaling to proliferate and differentiate into hair cells (Mizutari et al.). Chickens also ears have a thin F-actin belt that expresses little E-cadherin and allow the hairs to be regenerated by the supporting cells (Burns et al.). Once the hairs have been regenerated in the cochlea the specialized cells will stop proliferating.

Mizutari, K., M. Fujioka, M. Hosoya, N. Bramhall, H. J. Okano, H. Okano, and A. S. Edge. "Notch Inhibition Induces Cochlear Hair Cell Regeneration and Recovery of Hearing after Acoustic Trauma." *Neuron* 77.1 (2013): 58-69. *NCBI*. Web. 9 Dec. 2014. http://www.ncbi.nlm.nih.gov/pubmed/?term=Notch+inhibition+induces+cochlear+hair+cell+regeneration+and+recovery+of+hearing+after+acoustic+trauma

Burns, J. C., M. S. Collado, E. R. Oliver, and J. T. Corwin. "Specializations of Intercellular Junctions Are Associated with the Presence and Absence of Hair Cell Regeneration in Ears from Six Vertebrate Classes." *The Journal of Comparative Neurology* 521.6 (2013): 1430-448. *NCBI*. Web. 9 Dec. 2014.

http://www.ncbi.nlm.nih.gov/pubmed/23124808

65) Yellow aiptasia, Aiptasia diaphana

Yellow aiptasia can be found in the Mediterranean Sea and North Atlantic Ocean (Santos). Yellow aiptasia are a type of sea anemone and have the ability of regenerating their oral-disc.

After the injury the wound closes up by using the proliferated cells in the ectoderm near the wound site (Singer). As more cells are proliferated they form a layer that fuses the two sides of the injury closed. The ectoderm cells are found to not only help rebuild the oral disc but to regenerate the tentacle buds. The tentacle buds will then create a blastema to regenerate the tentacles. Cells in the endoderm also start to proliferate and differentiate to reform the pharynx (Singer). Gastrodermal cells have also been seen to migrate to the wounded area to help surround the zooxanthellae and keep them in place (Singer). Once the oral disc has regenerated, the cells closest to the wound will stop proliferating to heal it and other cells will be initiated to form the other parts that may have been amputated as well.

Santos, D. "Aiptasia Diaphana." *Aiptasia Diaphana, Yellow Aiptasia*. SeaLifeBase, 28 Aug. 2012. Web. 9 Dec. 2014 http://www.sealifebase.fisheries.ubc.ca/summary/Aiptasia-diaphana.html

Singer, Irwin I. "Tentacular and Oral-disc Regeneration in the Sea Anemone, Aiptasia Diaphana." *Journal of Embryology and Experimental Morphology* 26.2 (1971): 253-70. *Development*. Web. 9 Dec. 2014. http://dev.biologists.org/content/26/2/253.full.pdf?origin=publication_detail

66) American bullfrog, Rana catesbeiana

American bullfrogs can be found in Canada, Mexico, and the United States (Santos-Barrera et al.). These frogs are freshwater dwellers and lay their eggs in sacs in the water to develop. The American bullfrog tadpoles have the ability of regenerating their tail after it has been amputated in some way.

Shortly after the tail has been amputated epithelial cells migrate towards the wound. These cells proliferate and join together to form the new epithelium that covers the wound. Under the epithelium a blastema is formed from blastemal cells (Atkinson et al.). These cells are undifferentiated and proliferate to aid in the regeneration process. Macrophages swarm to the wound as well and clear the wound of any debris such as dead cells or infection. The blastema cells form the notochordal outgrowth and nerve axons in the newly regenerating tail (Atkinson et al.). Myoblasts are also found in the blastema where they fuse together and form the myotubules (Atkinson et al.). These myotubules develop into the musculature of the tail such as the muscle fibers and tendons. The epithelial cells also help to form capillaries that supply blood to the tail. Once the tail has reached its maximum size the blastema will disintegrate and the cells will stop proliferating and differentiating.

Santos-Barrera, G., Hammerson, G., Hedges, B., Joglar, R., Inchaustegui, S., Lue Kuangyang, Chou Wenhao, Gu Huiqing, Shi Haitao, Diesmos, A., Iskandar, D., van Dijk, P.P., Masafumi Matsui, Schmidt, B., Miaud, C. & Martínez-Solano, I. 2009. *Lithobates catesbeianus*. The IUCN Red List of Threatened Species. Version 2014.3. Web. 9 Dec. 2014.

http://www.iucnredlist.org/details/58565/0

Atkinson, Kristine H., Burr G. Atkinson, and Peter A. Merrifield. "Morphogenetic Sequences during Tadpole Tail Regeneration." *Canadian Journal of Zoology* 54.8 (1976): 1314-325. *NRC Research Press*. Web. 9 Dec. 2014. http://www.nrcresearchpress.com/doi/abs/10.1139/z76-149?journalCode=cjz#.VK83uWTUu8k

67) African clawed frog, Xenopus laevis

African clawed frogs can be found in South Africa, Namibia, and Angola (Garvey). Females are known to produce 500 to 2000 eggs at one time and they can reproduce multiple times during the year (Garvey). The tadpoles produced are able to regenerate a tail if it was amputated in some way.

After the tail is amputated off of the tadpole it uses the multipotent stem cells to regenerate its tail. Wnt, Fgf, Bmp, Notch and TGF-beta pathways have been found to activate the cells into proliferating and differentiating (Lin et al.). Muscle cells near the wound site proliferate and form a protective covering over the wound called the stump. Reactive oxygen species (ROS) are free radicals that have been known to be harmful in other species, but in the tadpole it increases the Wnt and Notch signaling (Love et al.). These signals activate spinal cord and notochord cells to proliferate and regenerate the spinal cord in the stump where the tail used to connect. Muscle satellite cells and melanophore precursors generate muscle and melanophores, respectively (Lin et al.). The stump continues to proliferate and grow as the spinal chord and muscles are growing. Once the tail reaches its maximum size the cells will stop differentiating to grow the cell but to keep the tail young.

Garvey, Nathan. "African Clawed Frog." *African Clawed Frog Fact Sheet*. Smithsonian National Zoological Park, 2014. Web. 9 Dec. 2014. http://nationalzoo.si.edu/Animals/ReptilesAmphibians/Facts/FactSheets/Africanclawedfrog.cfm

Love, Nick R., Yaoyao Chen, Shoko Ishibashi, Paraskevi Kritsiligkou, Robert Lee, Yvette Koh, Jennifer L. Gallop, Karel Dorey, and Enrique Amaya. "Amputation-induced Reactive Oxygen Species Are Required for Successful Xenopus Tadpole Tail Regeneration." *Nature Cell Biology* 15 (2013): 222-28. *Nature*. Web. 9 Dec. 2014. http://www.nature.com/ncb/journal/v15/n2/full/ncb2659.html

Lin, Gufa, and Jonathan M.W. Slack. "Requirement for Wnt and FGF Signaling in Xenopus Tadpole Tail Regeneration." *Developmental Biology* 316.2 (2008): 323-35. *ScienceDirect*. Web. 9 Dec. 2014. http://www.sciencedirect.com/science/article/pii/S0012160608000766

68) House mouse, Mus musculus

House mice are often found near civilizations where they can acquire an easy meal (Messer et al.). Mice have the ability of regenerating their taste buds if they were to ever get damaged.

Scientists have found that there are large numbers of perigemmal and basal epithelial cells in the fungiform section of the taste papillae. These cells are able to go through the mitosis cycle and produce asymmetrical transit amplifying (TA) daughter cells (Miura & Barlow). These cells then divide symmetrically and create immature taste cells that are stored in the taste buds. (Miura & Barlow). Basal keratinocytes also express transcription factors Trp63 which dedifferentiate epithelial stem cells and re-differentiate them into the epithelium of the tongue. Once the taste buds have regenerated the cells will stop proliferating and go back into the quiescent stage of mitosis.

Musser, G., Amori, G., Hutterer, R., Kryštufek, B., Yigit, N. & Mitsain, G. 2008. *Mus musculus*. The IUCN Red List of Threatened Species. Version 2014.3. Web. 9 Dec. 2014. http://www.iucnredlist.org/details/13972/0

Miura, Hirohito, and Linda A. Barlow. "Taste Bud Regeneration and the Search for Taste Progenitor Cells."*Archives Italiennes De Biologies* 148.2 (2010): 107-18. *NCBI*. Web. 9 Dec. 2014. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3545678/

69) Yellow aiptasia, Aiptasia diaphana

Yellow aiptasia can be found in the Mediterranean Sea, North Atlantic ocean, and the Red Sea (Van Der Land). Yellow aiptasia are a type of sea anemone and have the ability of regenerating their tentacles.

Soon after the sea anemone has lost its tentacle the regeneration process starts. Special undifferentiated cells will first migrate to the column and proliferate where the tentacle will be regenerated. These cells differentiate into epitheliomuscular cells that will form the structure of the developing tentacle (Singer). Other cells will differentiate into nephron cells that will form the sensory organs in the tentacle. Still other cells will proliferate and differentiate into nematocyst-containing cells that will migrate up the regenerated tentacle and protrude out of it to be able to use it properly (Singer). Once the tentacle has been regenerated to its maximum size the special undifferentiated cells will stop proliferating and disperse away from the column.

Van Der Land, Jacob. "Aiptasia Diaphana." *WoRMS - World Register of Marine Species - Aiptasia Diaphana (Rapp, 1829)*. WoRMS, 21 Dec. 2004. Web. 9 Dec. 2014. http://www.marinespecies.org/aphia.php?p=taxdetails&id=100858

Singer, Irwin I. "Tentacular and Oral-disc Regeneration in the Sea Anemone, Aiptasia Diaphana." *Journal of Embryology and Experimental Morphology* 26.2 (1971): 253-70. *Development*. Web. 9 Dec. 2014. http://dev.biologists.org/content/26/2/253.full.pdf?origin=publication_detail

70) Mexican Axolotl, Ambystoma mexicanum

The Mexican Axolotl is a salamander in the amphibian class. It can live 10 to 15 years in the wild but are considered endangered due to the water pollution, trading business, and being a food delicacy in Mexico ("Mexican Axolotls"). Axolotls have the unique ability of regenerating their spinal cord if it was to ever get damaged.

One of the major differences between urodeles and mammals is the microenvironment that the cells are housed in. The axolotl has many radial glial cells that are able to dedifferentiate, proliferate, and re-differentiate in a mesenchymal blastema that forms over the wound site (Gilbert). After the spinal cord is injured ependymal cells proliferate and interact with the extracellular matrix (ECM) to form the cranial and caudal ependymal outgrowths that connect to form the spinal cord (Chernoff). Macrophages also migrate to the wound and remove the dead neurons and neural cells. The axons are formed by the guidance of polysialyated-neural cell adhesion molecules (PS-N-CAM) controlling the re-differentiation of ependymal cells (Chernoff). Next the fibrous material surrounding the spinal cord creates muscles and tissues that differentiated from fibrous astrocytes (--). Once the axons, spinal cord, and surrounding muscles are formed the blastema will disintegrate and the cells will stop proliferating.

"Mexican Axolotls." *National Geographic*. National Geographic, n.d. Web. 9 Dec. 2014. http://animals.nationalgeographic.com/animals/amphibians/axolotl/

Gilbert, Scott F. "Regeneration." *Regeneration*. U.S. National Library of Medicine, 18 Dec. 2000. Web. 9 Dec. 2014. http://www.ncbi.nlm.nih.gov/books/NBK9971/

Chernoff, Ellen A.G. "Spinal Cord Regeneration: A Phenomenon Unique to Urodeles?" *International Journal of Developmental Biology* 40 (1996): 823-31. *IJDB*. Web. 9 Dec. 2014. www.ijdb.ehu.es/web/descarga/paper/8877457

71) Mexican Axolotl, Ambystoma mexicanum

The Mexican Axolotl is a salamander in the amphibian class. It can live 10 to 15 years in the wild but are considered endangered due to the water pollution, trading business, and being a food delicacy in Mexico ("Mexican Axolotls"). Axolotls have the unique ability of regenerating their skin to leave it scar-free.

The axolotls exhibit many juvenile characteristics when fully grown. One of those characteristics is having leydig cells still mixed in with the epithelial cells in the epidermis. Once the animal has been cut the blood clots but does not form a scab and over the next few day's blood cells can be seen in the wound bed (Gilbert). Epithelial cells also migrated over the wound accumulating plasma and re-epithelializing it (Seifert et al.). Fibroblasts start to migrate to the wound and deposit extracellular matrix between the epidermis and muscle. The epithelial cells also differentiate into the muscle fibers and other epidermal organs (Seifert et al.). Once the skin was completely regenerated the blastema would disintegrate which would stop the proliferation and differentiation of the epithelial cells.

"Mexican Axolotls." *National Geographic*. National Geographic, n.d. Web. 05 Nov. 2014. http://animals.nationalgeographic.com/animals/amphibians/axolotl/

Gilbert, Scott F. "Regeneration." *Regeneration*. U.S. National Library of Medicine, 18 Dec. 2000. Web. 05 Nov. 2014. http://www.ncbi.nlm.nih.gov/books/NBK9971/

Seifert, Ashley W., James R. Monaghan, S. Randal Voss, and Malcolm Maden. "Skin Regeneration in Adult Axolotls: A Blueprint for Scar-Free Healing in Vertebrates." *PLoSONE* (2012): n. pag. *PLoSONE*. Web. 5 Nov. 2014. http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0032875

72) Little skate, Leucoraja erinacea

Little skates can be found near Canada and the northeast United States (Sulikowski et al.). They look like rays and live in oceans. The Little skate has been found to have kidney regeneration capabilities.

After partial nephrectomy, nephrogenesis is induced to regenerate the missing portion of the kidney. It has been that the Little skate has a nephrogenic zone attached to its kidney. This zone contains mesenchymal cells and prospective tubular cells that are able to proliferate (Elger et al.). The mesenchymal cells would migrate and form tight junctions with one another to create a basement membrane (Elger et al.). Next the prospective tubular cells would migrate and join together to form elongated cysts that could bend and create tubular loops (Elger et al.). The gap at the end of the tube would close up from mesenchymal cells that had differentiated into epithelial cells and become the glomerular epithelial primordial (Elger et al.). After the gap was closed undifferentiated mesenchymal cells would attach to the prospective Boman's capsule and segments of the tubes would differentiate into nephron segments (Elger et al.). The cells would continue to proliferate and add onto the tubes to increase the kidney mass until it was at its maximum size. Once it was big enough the mesenchymal and tubular cells would stop proliferating and differentiating into the different parts of the kidney.

Sulikowski, J., Kulka, D.W. & Gedamke, T. 2009. *Leucoraja erinacea*. The IUCN Red List of Threatened Species. Version 2014.3. Web. 11 Dec. 2014. http://www.iucnredlist.org/details/161418/0

Elger, Marlies, Hartmut Hentschel, Jennifer Litteral, Maren Wellner, Torsten Kirsch, Friedrich C. Luft, and Hermann Haller. "Nephrogenesis Is Induced by Partial Nephrectomy in the Elasmobranch Leucoraja Erinacea." *Journal of the American Society of Nephrology* 14.6 (2003): 1506-518. *JASN*. Web. 11 Dec. 2014. http://jasn.asnjournals.org/content/14/6/1506.short

73) Rabbit, Lepus curpaeums

Rabbits can be found on every continent besides Antarctica. They have nearly 360-degree vision which means that their eyesight is very important to them (Bradford). If the rabbit's cornea was to get injured they have the ability of regenerating epithelium and nerves in the cornea.

After the cornea is damaged the epithelium is regenerated from cells that surround the wound and proliferate. The proliferated cells then join together and form an endothelial monolayer by day 10 (Van Horn et al.). The endothelial layer continues to develop until there is a fully functioning epithelium. Epithelial cells also start to secrete epithelial neuronotropic factor (ENF), which promotes the survival and neuron outgrowth (Chan et al.). Although, ENF does not start to have an impact until after the epithelium has been regeneration. Once the epithelium is regenerated ENF would signal regeneration of intraepithelial nerves. Keratocytes, epithelial, and endothelial cells dedifferentiate and then re-differentiate into nerve cells to form the new nerves in the cornea (He & Bazan).

Bradford, Alina. "Rabbits: Habits, Diet & Other Facts." *LiveScience*. TechMedia Network, 05 June 2014. Web. 25 Jan. 2015. http://www.livescience.com/28162-rabbits.html

Chan, K. Y., R. R. Jones, D. H. Bark, J. Swift, J. A. Parker, Jr., and R. H. Haschke. "Release of Neuronotrophic Factor from Rabbit Corneal Epithelium during Wound Healing and Nerve Regeneration." *Experimental Eye Research* 45.5 (1987): 633-46. *NCBI*. Web. 12 Dec. 2014.

http://www.ncbi.nlm.nih.gov/pubmed/3428389

Van Horn, Diane L., Deborah D. Sendele, Sam Seideman, and Paul J. Buco. "Regenerative Capacity of the Corneal Endothelium in Rabbit and Cat." *Investigative Ophthalmology & Visual Science* 16.7 (1977): 597-613. *Iovs*. Web. 12 Dec. 2014. http://www.iovs.org/content/16/7/597.short

He, Jiucheng, and Haydee E.P. Bazan. "Omega-3 Fatty Acids in Dry Eye and Corneal Nerve Regeneration after Refractive Surgery." *Prostaglandins Leukot Essential Fatty Acids* 82.4-6 (2010): 319-25. *NCBI*. Web. 13 Dec. 2014. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2856794/

74) Starlet sea anemone, Nematostella vectensis

Starlet sea anemone can be found in the Atlantic Ocean (World Conservation Monitoring Centre 1996). Starlet sea anemones have the ability of regenerating their oral disc after injury.

After the injury the wound closes up by using the proliferated cells in the ectoderm near the wound site (Passamaneck & Martindale). As more cells are proliferated they form a layer that fuses the two sides of the injury closed. The ectoderm cells are found to not only help rebuild the oral disc but to regenerate the tentacle buds. The tentacle buds will then create a blastema to regenerate the tentacles. Cells in the endoderm also start to proliferate and differentiate to reform the pharynx (Passamaneck & Martindale). Once the oral disc has regenerated the cells closest to the wound will stop proliferating to heal it and other cells will be initiated to form the other parts that may have been amputated as well.

World Conservation Monitoring Centre 1996. *Nematostella vectensis*. The IUCN Red List of Threatened Species. Version 2014.3. Web. 13 Dec. 2014. http://www.iucnredlist.org/details/14500/0

Passamaneck, Yale J., and Mark Q. Martindale. "Cell Proliferation Is Necessary for the Regeneration of Oral Structures in the Anthozoan Cnidarian Nematostella Vectensis." *BMC Developmental Biology* 12 (2012): 34.*BMC Developmental Biology*. Web. 13 Dec. 2014. http://www.biomedcentral.com/1471-213X/12/34

75) Zebrafish, Danio rerio

Zebrafish can be found in the tropical fresh waters of northern India, northern Pakistan, Nepal, and South Asia. They can grow up to 4-5 centimeters in length and get their name from stripes on their body (Hamel & Mercier). Zebrafish can also regenerate parts of their brain if it was to get injured.

Zebrafish are different from mammals in their regenerative capabilities when dealing with the brain because Zebrafish are continually proliferating their cells in progenitor zones in the brain. The progenitor zone houses stem/progenitor cells that can differentiate into whatever cell is needed at certain times (Kroehne et al.). They usually turn into radial glia progenitor cells that proliferate and generate neuroblasts, which help form neurons in the brain (Kroehne et al.). Once the brain is injured there needs to be a release of cysteinyl leukotriene to stimulate an acute inflammation at the site of injury or the brain can not regenerate itself (Kyritsis et al.). The acute inflammation has been show to induce neural progenitors and neurogenesis (Kyritsis et al.). Once the brain has been healed the inflammation will reduce and become non-existent and then the progenitor cells will stop proliferating and differentiating.

Hamel, J.-F. & Mercier, A. 2013. *Apostichopus japonicus*. The IUCN Red List of Threatened Species. Version 2014.3. Web. 13 Dec. 2014.
http://www.iucnredlist.org/details/180424/0

Kyritsis, N., C. Kizil, S. Zocher, V. Kroehne, J. Kaslin, D. Freudenreich, A. Iltzsche, and M. Brand. "Acute Inflammation Initiates the Regenerative Response in the Adult Zebrafish Brain." *Science* 338.6112 (2012): 1353-356. *NCBI*. Web. 14 Dec. 2014. http://www.ncbi.nlm.nih.gov/pubmed/23138980

Kroehne, Volker, Dorian Freudenreich, Stefan Hans, Jan Kaslin, and Michael Brand. "Regeneration of the Adult Zebrafish Brain from Neurogenic Radial Glia-type Progenitors." *Development* 138 (2011): 4831-841.*Development and Stem Cells*. Web. 14 Dec. 2014. http://dev.biologists.org/content/138/22/4831.abstract

76) Zebrafish, Danio rerio

Zebrafish can be found in the tropical fresh waters of northern India, northern Pakistan, Nepal, and South Asia. They can grow up to 4-5 centimeters in length and get their name from stripes on their body (Hamel & Mercier). Zebrafish can regenerate their photoreceptor cells if they were to get damaged so they can convert the light to the neurons so the brain knows what it is looking at.

After ablation of ultraviolet-sensitive (UV) cone photoreceptors in a specific subtype, or region, there was an increase of retinal neurons proliferating and were undifferentiated. BrdU and NTR-mCherry were seen on tests and are known to only be seen when the cells are proliferating (Fraser et al.). The newly replicated cells begin to differentiate into the UV cone photoreceptors. The cells knew to become UV cone photoreceptors by the expression of the UV opsin transgene (Fraser et al.). If the cones are damaged in a variety of subtypes, or regions, of the retina then the cells will be affected by the neighboring cells to turn into a certain cell due to the specific pattern of the heterotypic cell mosaic (Fraser et al.). This means that they don't have to turn into UV cone photoreceptors but can depending on what the pattern is depicting.

Hamel, J.-F. & Mercier, A. 2013. *Apostichopus japonicus*. The IUCN Red List of Threatened Species. Version 2014.3. Web. 14 Dec. 2014.
http://www.iucnredlist.org/details/180424/0

Fraser, Brittany, Michele G. DuVal, Hao Wang, and W. Ted Allison. "Regeneration of Cone Photoreceptors When Cell Ablation Is Primarily Restricted to a Particular Cone Subtype." *PLoSONE* (2013): n. pag. *PLoSONE*. Web. 14 Dec. 2014. http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0055410

77) Atlantic sand fiddler, Uca pugilator

Atlantic sand fiddlers can be found from Cape Cod to Texas, except not in Florida or St. Augustine (Patterson). They have one abnormally large pincer compared to the other smaller walking legs. Atlantic sand fiddlers have the unique ability of regenerating their legs after autonomy or forced removal.

Fiddler crabs are able to regenerate a lost limb during the intermolt cycle. Due to the fact that this is a crustacean it has a designated spot on the leg in which the leg is released and ensures the regeneration of another leg. For the crab to produce another leg it must go through a basal growth phase and a proecdysial growth phase. The basal growth phase begins after the limb is lost and first produces an autonomy membrane (AM) (Hopkins). The distal portion of the AM protrudes outward to seal the wound, while the proximal portion attaches to the sheath of the severed nerve (Hopkins). Fibroblast growth factors (FGFs) are produced to develop the blastema and direct the cells that are undifferentiated to re-differentiate into the needed muscles, tissues, and nerves of the leg (Hopkins). During the proecdysial phase the limb undergoes hypertrophic growth of the myotubules to allow for protein synthesis and water uptake (Hopkins). The intake of water and synthesis of protein allows the limb to fully develop and grow in size until it has reached its maximum size.

Patterson, Chris. "Uca Pugilator (Atlantic Sand Fiddler)." *Animal Diversity Web*. University of Michigan, 10 Dec. 2001. Web. 14 Dec. 2014. http://animaldiversity.org/accounts/Uca_pugilator/

Hopkins, Penny M. "Limb Regeneration in the Fiddler Crab, Uca Pugilator: Hormonal and Growth Factor Control." *American Zoology* 41.3 (2001): 389-98. *Integrative & Comparative Biology*. Web. 14 Dec. 2014. http://icb.oxfordjournals.org/content/41/3/389.full

78) Zebrafish, Danio rerio

Zebrafish can be found in the tropical fresh waters of northern India, northern Pakistan, Nepal, and South Asia. They can grow up to 4-5 centimeters in length and get their name from stripes on their body (Hamel & Mercier). Zebrafish can regenerate their spinal cord.

After the spinal cord is damaged multiple signals, such as Wnt, BMP/TGF beta, and JAK-STAT, are relayed to start the regeneration process (Hui et al.). One of those signals is the inflammatory response which allows macrophages to migrate to the wound and clear the debris. Microglial cells that are found to be stem cell-like migrate to the wound as well and start proliferating (Hui et al.). The cells will form a bridge connecting the two stumps together and differentiate into the spinal cord. Some of the cells will also differentiate into NeuroD positive cells and become neuron cells (Hui et al.). These cells will join together and form a neuroepithelium which will allow for nerve signals to be passed along (Hui et al.). The microglial cells also differentiate into various tissues that make up and surround the cord. Once the spinal cord and neurons have been regenerated the signals for regeneration will stop being produced and migrate away from the previous wound site.

Hamel, J.-F. & Mercier, A. 2013. *Apostichopus japonicus*. The IUCN Red List of Threatened Species. Version 2014.3. Web. 14 Dec. 2014.
http://www.iucnredlist.org/details/180424/0

Hui, Subhra Prakash, Dhriti Sengupta, Serene Gek Ping Lee, Triparna Sen, Sudip Kundu, Sinnakaruppan Mathavan, and Sukla Ghosh. "Genome Wide Expression Profiling during Spinal Cord Regeneration Identifies Comprehensive Cellular Responses in Zebrafish." *PLoSONE* (2014): n. pag. *PLoSONE*. Web. 15 Dec. 2014. http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0084212#s3

79) Atlantic tomcod, Microgadus tomcod

Atlantic tomcods can be found on the northeast coasts of the United States and Canada (NatureServe 2013). Tomcods have the ability of regenerating their kidney if it were to get damaged.

After the tomcod sustains kidney damage it will undergo an initial phase that involves macrophages destroying the dead cells and other debris. After that initial phase the kidney will start to produce signals that will help the kidney regenerate. Three signals have been found to be key and they are myc, Pax-2, and insulin-like growth factor-1 (Reimschuessel). The signals are used to trigger epithelial cells to converge on the damaged section of the kidney and proliferate. The proliferation will allow the basophilic epithelial basement membrane to repopulate (Reimschuessel). The tomcod will then undergo a nephron neogenesis phase to reestablish the nephrons in the newly regenerated section. The basophilic epithelium cells are used to form renal vesicles, S-shaped tubules, and tubular outgrowths which fuse to the collecting ducts (Reimschuessel). The epithelial parts are also used to form the Bowman's capsule. Once all of the structures in the previously damaged section of the kidney are formed, the cells will disperse and stop proliferating.

NatureServe 2013. *Microgadus tomcod*. The IUCN Red List of Threatened Species. Version 2014.3. Web. 28 Dec. 2014.
http://www.iucnredlist.org/details/202405/0

Reimschuessel, Renate. "A Fish Model of Renal Regeneration and Development." *ILAR Journal* 42.4 (2001): 285-91.*Oxford Journals*. Web. 28 Dec. 2014. http://ilarjournal.oxfordjournals.org/content/42/4/285.full

80) Japanese Spiky Sea Cucumber, Apostichopus japonicus

Japanese Spiky Sea Cucumbers are found in the Northwest Pacific ocean. It is currently on the Endangered species act after being exploited for its meat (Hamel & Mercier). They have the ability to regenerate respiratory trees in their body if they were eviscerated or damaged.

After the sea cucumber eviscerates or damages its respiratory trees they will undergo regeneration. Cells from the coelomic and luminal epithelia of the cloaca would dedifferentiate and migrate to the spot of re-differentiation. Peritoneocytes migrated as a united layer while myoepithelial cells disaggregated and migrated as individual cells (Dolmatov & Ginanova). It was also found that the myoepithelial cells did not proliferate during regeneration, whereas peritoneocytes did proliferate (Dolmatov & Ginanova). Once these cells migrated the myoepithelial cells would form the contractile system of the respiratory trees and the cloaca lining cells would form the luminal epithelium (Dolmatov & Ginanova). The regeneration of the respiratory trees allows the sea cucumber to breathe and survive.

Hamel, J.-F. & Mercier, A. 2013. *Apostichopus japonicus*. The IUCN Red List of Threatened Species. Version 2014.3. Web. 15 Dec. 2014.
http://www.iucnredlist.org/details/180424/0

Dolmatov, I. Y., and T. T. Ginanova. "Post-autotomy Regeneration of Respiratory Trees in the Holothurian Apostichopus Japonicus (Holothuroidea, Aspidochirotida)." *Cell and Tissue Research* 336.1 (2009): 41-58. *NCBI*. Web. 15 Dec. 2014.

http://www.ncbi.nlm.nih.gov/pubmed/19238446

81) Whitespotted Bamboo Shark, Chiloscyllium plagiosum

Whitespotted Bamboo Sharks can be found in the west Pacific Ocean (Kune & Burgess). The Whitespotted Bamboo Shark is capable of regenerating its liver after some sort of injury.

After the liver has undergone damage there are three target miRNAs that are signaled which are: hsa-miR-142-3p_R-1, xtr-miR-125b, and fru-miR-204 (Conger et al..). These three target miRNAs have been found to be generated more during the early and late times of regeneration which corresponds to apoptotic activity (Conger et al.). While these miRNAs are overexpressed the liver cannot undergo liver regeneration, but once they go back to normal levels hepatic stem cells are able to proliferate. These cells will proliferate and join together to form the missing parts of the liver. Once the liver has reached its maximum size and are not needed anymore miRNAs are generated as a negative feedback mechanism to stop cell proliferation (Conger et al.).

Kyne, P.M. & Burgess, G.H. 2006. *Chiloscyllium plagiosum*. The IUCN Red List of Threatened Species. Version 2014.3. Web. 17 Dec. 2014. http://www.iucnredlist.org/details/60222/0

Conger Lu, Jie Zhang, Zuoming Nie, et al., "Study of MicroRNAs Related to the Liver Regeneration of the Whitespotted Bamboo Shark, Chiloscyllium plagiosum," BioMed Research International, vol. 2013, Article ID 795676, 12 pages, 2013. Web 17 Dec. 2014. http://www.hindawi.com/journals/bmri/2013/795676/

82) Goldfish, Carassius auratus auratus

Goldfish were originally found in Eastern Asia but can now be found all over the world in freshwater ponds or streams (Nico et al.). The goldfish has the ability of regenerating its kidney if it was damaged in some way.

After the goldfish has sustained injury of the kidney it will undergo an initial phase of cell death and allow macrophages to clear them away. After this stage the kidney will start producing signals to regenerate. Three signals have been found to be key in helping initiate renal regeneration: myc, Pax-2, and insulin-like growth factor-1 (Reimschuessel). These signals trigger epithelial cells to migrate to the injured spot and start proliferating. These cells proliferate to repopulate the basophilic epithelial basement membrane (Reimschuessel). Then the fish undergoes a nephron neogenesis phase to reestablish the nephrons. The basophilic epithelium cells are used to form renal vesicles, S-shaped tubules, and tubular outgrowths which fuse with the collecting ducts (Reimschuessel). Then using the epithelial parts as well forms a Bowman's capsule. Once all of the structures have formed the cells will stop proliferating and disperse away from the injured site.

Nico, L. G., P. J. Schofield, J. Larson, T. H. Makled, and A. Fusaro. "Carassius Auratus." *Goldfish (Carassius Auratus) - FactSheet*. USGS Nonindigenous Aquatic Species Database, 2 Aug. 2013. Web. 17 Dec. 2014. http://nas.er.usgs.gov/queries/factsheet.aspx?speciesid=508

Reimschuessel, Renate. "A Fish Model of Renal Regeneration and Development." *ILAR Journal* 42.4 (2001): 285-91.*Oxford Journals*. Web. 18 Dec. 2014. http://ilarjournal.oxfordjournals.org/content/42/4/285.full

83) Green Anole, Anolis carolinensis

Green Anoles can be found in the Southeastern United States. They can grow up to eight inches and change colors to blend in to their surroundings (Crawford). The Green Anole is able to regenerate its tail if it was cut off or released to escape a predator.

Once the tail is severed a wound epithelium forms over the stump and vessels form to supply the area with blood (Hutchins et al.). Cells from surrounding tissues would dedifferentiate to supply the wound with the needed cells to regenerate the tail. The first thing that would grow is the ependymal from the spinal cord in the mesenchymal tissue (Hutchins et al.). The cells would re-differentiate into vascularized tissue, myofibers, cartilage tube, and surrounding skeletal muscles (Hutchins et al.). As the tail continued to grow by cell differentiation, myosin heavy chain positive skeletal muscle would become more prevalent along the tail helping to strengthen the tail (Hutchins et al.). Once the tail had grown back to its original length the cells would stop differentiating.

Crawford, Chelsea. "Anolis Carolinensis (Green Anole)." *ADW: Anolis Carolinensis*. Animal Diversity Web, 19 Mar. 2011. Web. 19 Dec. 2014. http://animaldiversity.org/site/accounts/information/Anolis_carolinensis.html

Hutchins, Elizabeth D., Glenn J. Markov, Walter L. Eckalbar, Rajani M. George, Jesse M. King, Minami A. Tokuyama, Lauren A. Geiger, Nataliya Emmert, Michael J. Ammar, April N. Allen, Ashley L. Siniard, Jason J. Corneveaux, Rebecca E. Fisher, Juli Wade, Dale F. DeNardo, J. Alan

Rawls, Matthew J. Huentelman, Jeanne Wilson-Rawls, and Kenro Kusumi. "Transcriptomic Analysis of Tail Regeneration in the Lizard Anolis Carolinensis Reveals Activation of Conserved Vertebrate Developmental and Repair Mechanisms." *PLoSONE* (2014): n. pag. *PLoSONE*. Web. 19 Dec. 2014. http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0105004

84) Chicken, Gallus gallus domesticus

Chickens can be found all over the world and are used for their meat and eggs. Chickens have the ability of regenerating their feathers once they fall off.

According to the article, *The developmental biology of feather follicles* written by Mingke Yu and colleagues, chickens first form the feather follicle with mesechymal cells that form periodically arranged condensations in the dermis. The mesechymal cells then interact with epithelial placodes to form the feather primordial that arrange in various patterns (Yu et al.). The feather primordia differentiate further to signal growth and cell adhesion molecules in the feather buds, which undergo cell proliferation, migration, and differentiation to form the feather follicles (Yu et al.). Yu and colleagues stated that the follicle wall has an outermost layer, which is the sheath that holds the feather in place until it disintegrates and the feather pops out. The middle layer and the inner basal layer will form the feather rachis and barbs (Yu et al.). The center is the mesenchymal pulp, which is composed of fibroblasts, fibronectin, laminin, and blood vessels (Yu et al.). Yu and colleagues stated that once the pulp degenerates the vanes of the feather open allowing the keratinocytes to flow from the collar through the dermal papilla and into the barb ridges and rachidial ridges to harden. The cells in the barb ridges then begin to differentiate into feather filaments that will be used to form the feather (Yu et al.).

Yu, Mingke, Zhicao Yue, Ping Wu, Da-Yu Wu, Julie-Ann Mayer, Marcus Medina, Randall B. Widelitz, Ting-Xin Jiang, and Cheng-Ming Chuong. "The Developmental Biology of Feather

Follicles." *International Journal of Developmental Biology* 48 (2004): 181-91. *USC Health Sciences*. Web. 19 Dec. 2014.

http://www-hsc.usc.edu/~cmchuong/2004DevBiol.pdf

85) Rat, Rattus

Rats can be found all over the world and can live for up to 5 years (“Rat”). Rats have the ability of regenerating their liver. After the liver has undergone some injury signals are sent to the bone marrow to produce and proliferate oval/progenitor cells (Laszlo et al.). These cells then migrated to the liver where they would differentiate into the hepatocytes. They would mature by hepatic mRNAs albumin, tryptophan 2,3-dioxygenase, and tyrosine aminotransferase that would insert into the cells and become their directions on what to become (Laszlo et al.). These cells would then join together and form the missing liver layers. Once the liver had been restored the bone marrow would stop producing oval/progenitor cells.

"Rat." *Rat (tus Tus)*. Http://a-z-animals.com/, 2013. Web. 19 Dec. 2014. http://a-z-animals.com/animals/rat/

Laszlo, V., K. Dezso, K. Baghy, V. Papp, I. Kovalszky, G. Safrany, S. S. Thorgeirsson, P. Nagy, and S. Paku. "Triiodothyronine Accelerates Differentiation of Rat Liver Progenitor Cells into Hepatocytes."*Histochemistry and Cell Biology* 130.5 (2008): 1005-014. *NCBI*. Web. 19 Dec. 2014. http://www.ncbi.nlm.nih.gov/pubmed/18663461

86) Laver spire snail, Hydrobia ulvae

Laver spire snails can be found off the coasts of Britain and northwest Europe ("Lavire Spire Shell"). These snails are good at gluing the sand and mud together on the ocean floor with their droppings. Laver spire snails have the ability of regenerating their head after decapitation.

Soon after the snail was decapitated the body wall muscle contracted to bring the two wound edges together and seal the wound. Once the walls were close enough the epithelial cells near the edges would proliferate and form the skin over the wound. This layer would also swell which were essentially blastemas. Some of the bulges would use the undifferentiated cells of the epithelium to proliferate and differentiate into small stick buds that would later form the tentacles (Gorbushin et al.). Other bulges appeared to get invaginations which would create the eyes. Then other undifferentiated cells not in the bulges would differentiate and form the proboscis, nose, of the snail (Gorbushin et al.). Another bud would form ventral to the wound scar and proliferate and differentiate cells into the propodium (Gorbushin et al.). Next black pigment would appear in the eye invaginations and other epithelial cells were forming the buccal complex and buccal ganglia could be found (Gorbushin et al.). Finally the unpigmented bodies of the skin gradually became pigmented. Once all of the structures of the head had been formed from proliferation and differentiation the epithelium would stop producing cells used for regeneration.

"Laver Spire Shell." *Laver Spire Shell Videos, Photos, and Data*. Wildscreen Arkive, 2014. Web. 20 Dec. 2014.
http://www.arkive.org/laver-spire-shell/hydrobia-ulvae/

Gorbushin, Alexander M., Ivan A. Levakin, Nadejda A. Panchina, and Yuri V. Panchin. "HYDROBIA ULVAE (GASTROPODA: PROSOBRANCHIA): A NEW MODEL FOR REGENERATION STUDIES." *The Journal of Experimental Biology* 204 (2001): 283-89. *The Journal of Experimental Biology*. Web. 20 Dec. 2014. http://jeb.biologists.org/content/204/2/283.full.pdf

87) African clawed frog, Xenopus laevis

African clawed frogs can be found in South Africa, Namibia, and Angola (Garvey). These creatures do not have a moveable eyelid but rather a horny, transparent covering that protects their eye from harm. African clawed frog larvae are able to regenerate their lens in the eye if the covering is injured or not fully developed.

Lens regeneration is controlled by trans-differentiation of the cells in the cornea. There are certain factors that help stimulate and control differentiation and they are able to accumulate in the vitreous chamber once the lens has been damaged. Once factor, FGF-1, can be found inducing trans-differentiation of the pigment epithelial cells (Rio-Tsonis & Tsonis). Once the cells have been dedifferentiated from the cornea they re-differentiate into lens cells. FGF-1 will stop the trans-differentiation process once the lens has been completely restored.

Garvey, Nathan. "African Clawed Frog." *ADW: Xenopus Laevis: INFO*. Animal Diversity Web, 4 Oct. 2000. Web. 20 Dec. 2014. http://nationalzoo.si.edu/Animals/ReptilesAmphibians/Facts/FactSheets/Africanclawedfrog.cfm

Rio-Tsonis, Katia Del, and Panagiotis A. Tsonis. "Eye Regeneration at the Molecular Age." *Developmental Dynamics* 226 (2003): 211-24. *Miami University*. Web. 20 Dec. 2014. http://www.units.miamioh.edu/regenerationlab/site/Publications_files/DevDynReviewfinal_review%205.pdf

88) Deepwater Spiny Dogfish, Centrophorus squamos

Deepwater Spiny Dogfish are found in the Atlantic, Indian, and Pacific Oceans (White). Deepwater Spiny Dogfish are capable of regenerating their kidney if it had been damaged.

After partial nephrectomy, nephrogenesis is induced to regenerate the missing portion of the kidney. It has been that the Deepwater Spiny Dogfish has a nephrogenic zone attached to its kidney. This zone contains mesenchymal cells and prospective tubular cells that are able to proliferate (Elger et al.). The mesenchymal cells would migrate and form tight junctions with one another to create a basement membrane (Elger et al.). Next the prospective tubular cells would migrate and join together to form elongated cysts that could bend and create tubular loops (Elger et al.). The gap at the end of the tube would close up from mesenchymal cells that had differentiated into epithelial cells and become the glomerular epithelial primordial (Elger et al.). After the gap was closed undifferentiated mesenchymal cells would attach to the prospective Boman's capsule and segments of the tubes would differentiate into nephron segments (Elger et al.). The cells would continue to proliferate and add onto the tubes to increase the kidney mass until it was at its maximum size. Once it was big enough the mesenchymal and tubular cells would stop proliferating and differentiating into the different parts of the kidney.

White, W.T. (SSG Australia & Oceania Regional Workshop, March 2003) 2003. *Centrophorus squamosus*. The IUCN Red List of Threatened Species. Version 2014.3. Web. 20 Dec. 2014. http://www.iucnredlist.org/details/41871/0

Elger, Marlies, Hartmut Hentschel, Jennifer Litteral, Maren Wellner, Torsten Kirsch, Friedrich C. Luft, and Hermann Haller. "Nephrogenesis Is Induced by Partial Nephrectomy in the Elasmobranch Leucoraja Erinacea." *Journal of the American Society of Nephrology* 14.6 (2003): 1506-518. *JASN*. Web. 20 Dec. 2104. http://jasn.asnjournals.org/content/14/6/1506.short

89) Common leopard gecko, Eublepharis macularius

Common leopard geckos can be found in the Middle East (Woods). These geckos are able to autotomize their tails if they get in danger. The leopard gecko has the ability of regenerating its tail after it is lost from an accident or foul play.

After tail is lost the spinal cord retracts further into the body and a blood clot is produced at the end to keep it from bleeding out. The walls closest to the wound essentially collapse and cover the wound area. A blastula is formed over the wound and houses epithelial and endothelial cells, myoblasts, osteoclasts, and chondroclasts (McLean & Vickaryous). Next, epithelial cells will proliferate and form the various layers of tissue in the tail. The epithelial cells are dedifferentiated and then re-differentiated into nerve cells that will form the axons of the nervous system in the tail. Endothelial cells are also seen proliferating and differentiating into blood vessels in the epithelium. Some of the cells in the blastema also differentiate into myoblasts that will proliferate and help the tail grow larger and longer by forming the cartilage (McLean & Vickaryous). As the tail is getting longer osteoclasts mature into chondroclasts and form the bone structure in the tail. Once the tail has elongated the epithelial cells become keratinized and epidermal scales begin to form and the skin gets fully pigmented (McLean & Vickaryous). As soon as the tail has been fully formed from the various types of cells proliferating and differentiating the blastula will disintegrate and the cells will go back into the quiescent stage of mitosis.

Woods, Vickie. "Eublepharis Macularius." *ADW: Eublepharis Macularius*. Animal Diversity Web, 20 Jan. 2001. Web. 20 Dec. 2014. http://animaldiversity.org/accounts/Eublepharis_macularius/

McLean, Katherine E., and Matthew K. Vickaryous. "A Novel Amniote Model of Epimorphic Regeneration: The Leopard Gecko, Eublepharis Macularius." *BMC Developmental Biology* 11 (2011): 50. *BMC Developmental Biology*. Web. 20 Dec. 2014. http://www.biomedcentral.com/1471-213X/11/50

90) Eastern (red-spotted) newt, Notophthalmus viridescens

Eastern (red-spotted) newts can be found in the eastern states of the United States and the adjacent southern land of Canada (IUCN SSC Amphibian Specialist Group 2014). This newt has the ability of regenerating its heart if it was ever damaged.

Soon after the heart sustains damage it starts to undergo regeneration. Fibrin migrates to the wound area to clot the blood so the animal will not die from blood loss. A protein called Phospho-H3 was also found to be emitted after the injury which stimulates cells to go into the G2 phase of the cell cycle to proliferate (Max-Planck-Gesellschaft). The cells that it stimulates are the cardiomyocytes that are surrounding the damage area. These cells are immature cardiomyocytes at first but as more are produced they mature into cardiomyocytes which differentiate into the cardiac muscle (Witman et al.). Once the heart has reached its maximum size and has completely regenerated the cardiomyocytes will stop proliferating and go back into the quiescent stage of mitosis.

IUCN SSC Amphibian Specialist Group 2014. *Notophthalmus viridescens*. The IUCN Red List of Threatened Species. Version 2014.3. Web. 20 Dec. 2014. http://www.iucnredlist.org/details/59453/0

Max-Planck-Gesellschaft. Cell Biology. *Newts Which Regrow Their Hearts*. *Research: Research News*. Max-Planck-Gesellschaft, 5 Dec. 2006. Web. 20 Dec. 2014. http://www.mpg.de/530203/pressRelease200612052

Witman, Nevin, Bari Murtuza, Ben Davis, Anders Arner, and Jamie Ian Morrison. "Recapitulation of Developmental Cardiogenesis Governs the Morphological and Functional Regeneration of Adult Newt Hearts following Injury." *Developmental Biology* 354.1 (2011): 67-76. *ScienceDirect*. Web. 20 Dec. 2014. http://www.sciencedirect.com/science/article/pii/S0012160611001850

91) Japanese rice fish, Oryzias latipes

Japanese rice fish or Medakas can be found near Southeast Asia in ponds, streams or rice paddies (Luna). They can range in size from 2- 4 centimeters long (Luna). Medakas have the ability to regenerate their kidney if it was to get damaged.

Soon after the kidney has sustained injury it will undergo some cell apoptosis in the tubular epithelia and glomeruli (Watanabe et al.). This causes the epithelial basement membrane to be stripped of its cells, while cysts form on the glomular and tubular segments. Signals are then sent for the epithelial cells to start proliferating near the wounded site. This helps repopulate the basement membrane and other structures in the kidney. After this occurs a de novo neogenesis phase occurs that will mature the structures in the kidney (Watanabe et al.). The basophilic epithelium cells proliferate and form the renal vesicles, S-shaped tubules, and tubular outgrowths to fuse with the collecting duct (Watanabe et al.). The Bowman's capsule is then made from the epithelial cells that have proliferated and matured. When all of the structures in the kidney have regenerated to their maximum size the cells will stop proliferating and disperse away from the previously wounded site.

Luna, Susan M. "Oryzias Latipes." *Oryzias Latipes, Japanese Rice Fish Summary*. FishBase, 27 Feb. 2012. Web. 20 Dec. 2014.
http://www.fishbase.org/summary/4669

Watanabe, Naoki, Mitsuhiro Kato, Norihiko Suzuki, Chikako Inoue, Svetlana Fedorova, Hisashi Hashimoto, Shoichi Maruyama, Seiichi Matsuo, and Yuko Wakamatsu. "Kidney Regeneration through Nephron Neogenesis in Medaka." *Development, Growth, & Differentiation* 51.2 (2009): 135-43. *Wiley Online Library*. Web. 20 Dec. 2014. http://onlinelibrary.wiley.com/doi/10.1111/j.1440-169X.2009.01090.x/full

92) Megarian Banded Centipede, Scolopendra cingulata

Mediterranean Banded Centipedes can be found near the Mediterranean sea (McMillion & Yach). This centipede is able to regenerate its midgut after it has been damaged in some way.

The migut of this centipede has regenerative cells that are able to begin the mitosis pahse in the day and divide at night (Chajec et al.). The regenerative cells are found in the basal lamina of the midgut and are treated as multipotent stem cells (Chajec et al.). After the midgut is injured the regenerative cells begin to proliferate and acculumate in the epithelium. In the cytoplasm of the regenerative cells are many mitochondria, autophagosomes, and multivesicular bodies (Chajec et al.). Mitochondria's are used to help proliferate and differentiate the cells in the epithelium. Autophagosomes promote cell survival which helps the epithelium structurally sound. Multivesicular bodies also help in protecting the epithelium from harm. The regenerative cells divide into a midgut stem cell, which differentiates into secretory cells, and a midgut progenitor cell, which differentiates into digestive cells (Chajec et al.). The regenerative cells continue to divide and to regenerate the midgut epithelium until it has been fully reformed. Once the midgut has regenerated the cells will stop dividing and go into the quiescent stage of mitosis.

McMillion, Andre, and Jaelen Yach. "Megarian Banded Centipede." *UWL Website*. University of Wisconsin, 2014. Web. 20 Dec. 2014. http://bioweb.uwlax.edu/bio203/s2014/mcmillio_andr/habitat.htm

Chajec, Tukasz, Lidia Sonakowskia, and Magdalena M. Rost-Roszkowska. "The Fine Structure of the Midgut Epithelium in a Centipede, Scolopendra Cingulata (Chilopoda, Scolopendridae), with the Special Emphasis on Epithelial Regeneration." *Arthropod Structure & Development* 43.1 (2014): 27-42. *Science Direct*. Web. 20 Dec. 2014. http://www.sciencedirect.com/science/article/pii/S1467803913000583

93) American five-lined skink, Plestiodon fasciatus

American five-lined skinks can be found in Canada and the Eastern states of the United States (Hammerson). When they are juveniles they are commonly called the blue-tailed skink and when they become an adult it is a red-headed skink. These skinks are able to regenerate their tail if it was torn off or fell off due to autonomy.

After the tail has been amputated the cells near the wound proliferate and form a wound epithelium over the stump. The endothelial cells near the wound start to proliferate and differentiate into the blood vessels that will supply the area with blood (Hutchins et al.). Epithelial cells also migrate to the wound, become dedifferentiated, and proliferate. The cells first start to form the ependymal from the spinal cord in the mesenchymal tissue (Hutchins et al.). Next the undifferentiated epithelial cells differentiate into chondrocytes that help form the cartilage in the newly regenerating tail. The dedifferentiated epithelial cells also re-differentiate into myofibers that would join together and form the muscles that surround the internal structures. As the tail continues to grow, myosin heavy chain positive skeletal muscle would become more prevalent along the tail to strengthen it (Hutchins et al.). Once the tail has completely regenerated the original cells would stop differentiating and disperse away from the previously wounded site.

Hammerson, G.A. 2007. *Plestiodon fasciatus*. The IUCN Red List of Threatened Species. Version 2014.3. Web. 22 Dec. 2014. http://www.iucnredlist.org/details/64227/0

Hutchins, Elizabeth D., Glenn J. Markov, Walter L. Eckalbar, Rajani M. George, Jesse M. King, Minami A. Tokuyama, Lauren A. Geiger, Nataliya Emmert, Michael J. Ammar, April N. Allen, Ashley L. Siniard, Jason J. Corneveaux, Rebecca E. Fisher, Juli Wade, Dale F. DeNardo, J. Alan Rawls, Matthew J. Huentelman, Jeanne Wilson-Rawls, and Kenro Kusumi. "Transcriptomic Analysis of Tail Regeneration in the Lizard Anolis Carolinensis Reveals Activation of Conserved Vertebrate Developmental and Repair Mechanisms." *PLoSONE* (2014): n. pag. *PLoSONE*. Web. 22 Dec. 2014. http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0105004

94) Chicken, Gallus gallus domesticus

Chickens can be found all over the world and are used for their meat and eggs. Chick embryos have the ability of regenerating their elbow joint.

Joints are key in forming a limb and are essential in everyday life. After the joint has been damaged or removed a joint interzone is formed from flattened noncartilagenous joint progenitor cells (Ozpolat et al.). The interzone helps to make the collagen become segmented and allow the joint to grow. The progenitors make it so Autotaxin and GDF-5 joint specific markers are only found in the interzone (Opolat et al.). This will allow the joints to be only formed in the zones and not at random. After, the cells in the interzone differentiate into three layers based on their densities. The higher density cells become the two articular cartilage layers that cover the surface of the bones where they meet with the joints (Ozpolat et al). The other layer is in between the two denser layers and gradually disappears through cavitation. Once the joint has been regenerated the cells stop differentiating.

Ozpolat, B. Duygu, Mariana Zapata, John Daniel Fruge, Jeffrey Coote, Jangwoo Lee, Ken Muneoka, and Rosalie Anderson. "Developmental Biology." *Developmental Biology* 372.2 (2012): 229-38. *ScienceDirect*. Web. 22 Dec. 2014. http://www.sciencedirect.com/science/article/pii/S0012160612005404

95) Common fruit fly, Drosophila melanogaster

Common fruit flies can be found on every continent, except Antarctica (Miller). Fruit flies are able to regenerate their leg if they were to get amputated or torn off.

At first the JNK phosphatase, puckered (puc), is signaled to proliferate the epidermal cells surrounding the wound (King & Newmark). The peripodial and columnar cells proliferate and merge together by microvilli (King & Newmark). The epithelial cells continue to proliferate to form new layers that will later mature into the skin. A blastema is formed, by the expression of Wg/Wnt1, over the wound that houses undifferentiated local epithelial cells (Bosch et al.). At first the cells proliferate and differentiate into proximal cells that make up the disc. Then myoblasts are signaled by m and ap to migrate to the wound and start proliferating. Myoblasts will fuse together and form the skeletal muscle as more signals are given to extend the arm. Next, ventral *wg*-expressing and dorsal *dpp*-expressing cells start proliferating and activate *DII (Bosch et al.)*. *DII* is found to activate EGFR which signals for the distal leg to start regenerating (Bosch et al.). Once the leg disc, tarsus and pretarsus are formed the signals for cell proliferation will stop and the blastema will disintegrate.

Miller, Conrad. "Drosophila Melanogaster." *ADW: Drosophila Melanogaster*. Animal Diversity Web, 4 Oct. 2000. Web. 23 Dec. 2014. http://animaldiversity.org/accounts/Drosophila_melanogaster/

Bosch, Manel, Sarah-Anne Bishop, Jaume Baguna, and Juan-Pablo Couso. "Leg Regeneration in Drosophila Abridges the Normal Developmental Program." *The International Journal of Developmental Biology* 54 (8-9): 1241-250.*ResearchGate*. Web. 22 Dec. 2014. https://www.researchgate.net/publication/44688549_Leg_regeneration_in_Drosophila_abridges_the_normal_developmental_program

King, Ryan S., and Phillip A. Newmark. "The Cell Biology of Regeneration." *JCB* 196.5 (2012): 553-62. *The Rockefeller University Press*. Web. 23 Dec. 2014. http://jcb.rupress.org/content/196/5/553.full

96) Eastern (red-spotted) newt, Notophthalmus viridescens

Eastern (red-spotted) newts can be found in the eastern states of the United States and the adjacent southern land of Canada (IUCN SSC Amphibian Specialist Group 2014). These newts have the ability of regenerating their spinal cord and central nervous system if it was to get injured.

Soon after the spinal cord has been injured neural stem and radial glial cells start to dedifferentiate and proliferate to form a mesenchymal blastema over the wound (Chernoff). The cells in the blastema start to differentiate into ependymal cells that join with the extracellular matrix to form the cranial and caudal ependymal outrgowths that connect the two cut ends of the spinal cord (Chernoff). Macrophages converge on the wound site to rid it of dead cells or infection. Next the axons are formed from the neural stem cells that proliferated and differentiated. Radial glial cells are then used to create the myelin network that surrounds the axons and protects it from injury. Finally mesenchymal cells proliferate and differentiate into fibrous astrocytes that form the muscles and tissues surrounding the spinal cord (Kageyama & Yamamori). Once the spinal cord, axons, and surrounding muscles are formed the blastema disintegrates and the neural stem and radial glial cells disperse away from the previously injured wound.

IUCN SSC Amphibian Specialist Group 2014. *Notophthalmus viridescens*. The IUCN Red List of Threatened Species. Version 2014.3. Web. 23 Dec. 2014. http://www.iucnredlist.org/details/59453/0

Chernoff, Ellen A.G. "Spinal Cord Regeneration: A Phenomenon Unique to Urodeles?" *International Journal of Developmental Biology* 40 (1996): 823-31. *IJDB*. Web. 23 Dec. 2014. www.ijdb.ehu.es/web/descarga/paper/8877457

Kageyama, Ryoichiro, and Tetsuo Yamamori. "Regulatory Mechanisms Underlying the Neurogenesis-to-Gliogenesis Switch by Neural Stem Cells." *Cortical Development Neural Diversity and Neocortical Organization*. Dordrecht: Springer, 2013. 63-89. Print.

97) Chicken, Gallus gallus domesticus

Chickens can be found all over the world and are used for their meat and eggs. Chickens have been found to have the capacity to regenerate their retinal neurons if they were to get damaged.

It has been found that postnatal chickens have a proliferating marginal zone on the retina. The zone contains undifferentiated retina progenitor cells that originated from Muller glial cells and can help the retina regenerate (Fischer & Thomas). Notch pathway signals for the dedifferentiation of Muller cells to progenitor cells. Once they have become progenitor cells they can proliferate and re-differentiate into neurons in the eye. Although for them to become neurons Notch signaling pathway must be down-regulated (Hayes et al.). Once all of the damaged neurons have been replaced with new ones the Muller glial cells will stop proliferating.

Fischer, Andy J., and Thomas A. Reh. "Identification of a Proliferating Marginal Zone of Retinal Progenitors in Postnatal Chickens." *Developmental Biology* 220 (2000): 197-210. *University of Washington*. Web. 23 Dec. 2014. http://faculty.washington.edu/tomreh/wordpress/wp-content/uploads/2009/01/fischerreh2000db.pdf

Hayes, Susan, Branden R. Nelson, Brian Buckingham, and Thomas A. Reh. "Notch Signaling Regulates Regeneration in the Avian Retina." *Developmental Biology* 312.1 (2008): 300-11. *NCBI*. Web. 24 Dec. 2014. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2170876/

98) Oyster toadfish, Opsanus tau

Oyster toadfish can be found from Maine to the Caribbean Sea (Froese). The Oyster toadfish has the capability of regenerating its kidney if it was to get damaged.

Soon after the Toadfishes kidney has been injured macrophages will converge on the wound and clear the dead cells and debris away. Next the kidney will start producing certain signals to initiate renal regeneration, which are myc, Pax-2, and insulin-like growth factor-1 (Reimschuessel). The signals target epithelial cells to migrate to the injured portion of the kidney and start proliferating. At first these cells are used to repopulate the basophilic epithelial basement membrane (Reimschuessel). Then the fish undergoes a nephron neogenesis pahse to reestablish the nephrons. Renal vesicles, S-shaped tubules, and tubular outgrowths are made from the basophilic epithelium cells (Reimschuessel). All of those structures fuse with the collecting duct to form the various kidney structures. Then the Bowman's capsule is formed using the epithelial parts. Once all of the structures have been formed the cells will stop proliferating and disperse away from the injured site.

Froese, Rainer. "Opsanus Tau." *Opsanus Tau, Oyster Toadfish Summary*. Fishbase, 19 May 2014. Web. 27 Dec. 2014. http://www.fishbase.org/summary/3069

Reimschuessel, Renate. "A Fish Model of Renal Regeneration and Development." *ILAR Journal* 42.4 (2001): 285-91.*Oxford Journals*. Web. 27 Dec. 2014.

http://ilarjournal.oxfordjournals.org/content/42/4/285.full

99) House mouse, Mus musculus

House mice are often found near civilizations where they can acquire an easy meal (Musser et al.). The adult mouse has the capability to regenerate the tip of their digits on their paws.

Soon after the digit has been amputated the epithelial cells surrounding the wound site undergo proliferation. The epithelial cells will help reform the layer of skin to cover the wounded area which doesn't fully reform until the bone has been regenerated. A blastema will also form over the wound which is comprised of vimentin, mesenchymal markers, epithelial and endothelial cells (Fernando et al.). Vimentin is a protein used to form the intermediate filaments in the digit (Satelli et al.). The mesenechymal markers help the undifferentiated mesenchymal cells to redifferentiate into specific cells to form structures in the digit. The mesechymal cells are used to form connective tissues with osteoblasts within the layers of the tissue (Tamarkin). As the osteoblasts mature they form the bones extracellular matrix as a spongy bone (Tamarkin). The osteoblasts mature into osteocytes and which can form the periosteum around the outside of the spongy bone. Once the bone is reformed osteoclasts start to proliferate and degrade the stump bone to allow the wound epidermis to form over the distal bone tip (Tamarkin). Endothelial cells also proliferate to form the muscle tissue surrounding the bone. Once all of the structures have been regenerated the blastema will disintegrate and the cells will go back into the quiescent stage of mitosis.

Musser, G., Amori, G., Hutterer, R., Kryštufek, B., Yigit, N. & Mitsain, G. 2008. *Mus musculus*. The IUCN Red List of Threatened Species. Version 2014.3. Web. 27 Dec. 2014.

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Fernando, W. A., E. Leininger, J. Simkin, N. Li, C. A. Malcom, S. Sathyamoorthi, M. Han, and K. Muneoka. "Wound Healing and Blastema Formation in Regenerating Digit Tips of Adult Mice." *Developmental Biology* 350.2 (2011): 301-10. *NCBI*. Web. 27 Dec. 2014. http://www.ncbi.nlm.nih.gov/pubmed/21145316

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Tamarkin, Dawn A. "Bone Development and Growth." *Bone Development and Growth*. Springfield Technical Community College, 2011. Web. 27 Dec. 2014. http://faculty.stcc.edu/AandP/AP/AP1pages/Units5to9/bone/bonedev.htm

100) Blackback land crab, Gecarcinus lateralis

Blackback land crabs can be found along the coasts of eastern states of the United States and the Gulf of Mexico (United States). This crab lives on the beaches for most of their lives until they are reproducing, then they go to the oceans and lay they egg. Land crabs have the ability of regenerating their leg if it was torn off or autotomized.

Soon after the limb is lost a scab is formed over the wound from coagulation. The membrane nearest the breakage plane also stretches to cover the wound. Epithelial, endothelial, and mesenchyme cells migrate to the injured site and begin to proliferate. The mesenchyme cells differentiate into the tissue of the new limb and create a small projection from out of the scab (Holland & Skinner). The tissues then begin to arrange into segments to form the various parts of the leg. Mesenchyme cells also differentiate into chondrocytes that form the muscle in the basi-ischium where the limb autotomy occurs (Holland & Skinner). Once the limb grows to a certain point it will begin preparing for ecdysis by first allowing the epidermis to separate from the old exoskeleton (Holland & Skinner). The cells in the epidermis begin to enlarge and synthesize the new epi- and exocuticular layers on the exoskeleton which will be able to grow once the old exoskeleton has been removed (Holland & Skinner). When the exoskeleton is lost a regenerated leg will emerge that can be used like all the other legs.

United States. National Park Service. "Blackback Land Crab." *National Parks Service*. U.S. Department of the Interior, 28 Dec. 2014. Web. 28 Dec. 2014. http://www.nps.gov/pais/naturescience/blackback_crab.htm

Holland, Christie A., and Dorothy M. Skinner. "INTERACTIONS BETWEEN MOLTING AND REGENERATION IN THE LAND CRAB." *Biological Bulletin* 150 (1976): 222-40. *Biological Bulletin*. Web. 28 Dec. 2014.

http://www.biolbull.org/content/150/2/222.full.pdf

101) Catfish, Siluriformes

Catfish can be found on every continent except Antarctica in freshwater habitat (“Catfish”). Catfish have the ability of regenerating their kidney if it were to get damaged.

After the catfish has sustained injury to the kidney it will undergo an initial phase of cell death and allow macrophages to clear them away. The kidney next will start producing signals to help initiate kidney regeneration. Three signals that are key for regeneration are myc, Pax-2, and insulin-like growth factor-1 (Reimschuessel). These signals trigger epithelial cells to migrate to the inured spot and start proliferating. The proliferation will help repopulate the basophilic epithelial basement membrane (Reimschuessel). A nephron neogenesis phase will follow to reestablish the nephrons. The basophilic epithelium cells are used to form renal vesicles, S-shaped tubules, and tubular outgrowths which fuse with the collecting ducts (Reimschuessel). Then the Bowman’s capsules are made using the epithelial parts. Once all of the structures have formed the cells will stop proliferating and disperse away from the injured site.

"Catfish." *Catfish (Siluriformes)*. A-z-animals, 2013. Web. 27 Dec. 2014. http://a-z-animals.com/animals/catfish/

Reimschuessel, Renate. "A Fish Model of Renal Regeneration and Development." *ILAR Journal* 42.4 (2001): 285-91.*Oxford Journals*. Web. 27 Dec. 2014. http://ilarjournal.oxfordjournals.org/content/42/4/285.full

102) Rainbow trout, Oncorhynchus mykiss

Rainbow trout are native to North America but have been introduced to every other continent besides Antarctica ("Rainbow-Trout-or-Steelhead"). Rainbow trout have the ability of regenerating their kidney if it were to get damaged.

Soon after the rainbow trout has kidney damage macrophages will converge on the injured site and phagocytize the dead cells and other debris. After this stage the kidney will start producing signals that will help the kidney regenerate. The signals are myc, Pax-2, and insulin-like growth factor-1 (Reimschuessel). These signals help initiate the epithelial cells to migrate and start proliferating at the injured section. The cells are used to repopulate the basophilic epithelial basement membrane (Reimschuessel). Then the fish will undergo a nephron neogenesis phase to reestablish the nephrons in the newly regenerated section. The basophilic epithelium cells are used to form the renal vesicles, S-shaped tubules, and tubular outgrowths which fuse with the collecting ducts (Reimschuessel). The Bowman's capsule is also made by using the epithelial cells and parts. Once all of the structures for the kidney have been formed the cells will disperse away from the previously injured section and stop proliferating.

"Rainbow-Trout-or-Steelhead." *Rainbow-Trout-or-Steelhead - National Wildlife Federation*. National Wildlife Federation, 2014. Web. 28 Dec. 2014. http://www.nwf.org/wildlife/wildlife-library/amphibians-reptiles-and-fish/rainbow-trout-or-steelhead.aspx

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103) Brown garden snail, Cornu aspersum

The Brown garden snail can be found all over the world but was native to Italy. This snail is highly regarded as a food delicacy as a source of escargot (Dekle). The Brown garden snail has the capability of regenerating a tentacle if it was to get torn or cut off.

To survive a wound the snail must have good healing and regeneration capabilities. Shortly after it is wounded the snails body secretes a natural regenerative substance they are calling SCA (Cruz et al.). This substance helps cells migrate to the wound and begin the regeneration processes. They activate keratinocytes and fibroblasts to migrate to the wound and start proliferating (Cruz et al.). The keratinocytes help create a new epithelium layer to close the wound and allow the tissue below the epithelium to regenerate. Once the new epithelium is built a blastema will form allowing the amoebocytes, keratinocytes, endothelial cells, and fibroblasts to continue to proliferate (Moffett). The fibroblasts then form the tissue that will make the tentacle structurally sound as it is being regenerated. The endothelial cells next begin to proliferate and create nerves and blood vessels in the tentacle as it grows (Moffett). Other cells then begin to make the sensory plate which will form the olfactory epithelium and eye (Moffett). All the while the amoebocytes are destroying all of the dead cells that were left over from the damage. Once the tentacle and all of its structures have been completely regenerated the blastema will disintegrate and the cells will stop proliferating.

Dekle, G. W. "Brown Garden Snail." *Brown Garden Snail - Cornu Asperum (Müller)*. University of Florida, Oct. 2001. Web. 27 Jan. 2015.

http://entomology.ifas.ufl.edu/creatures/misc/gastro/brown_garden_snail.htm

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104) Nile tilapia, Oreochromis niloticus

Nile tilapias originated from Africa but have been spread to other tropic and subtropic areas ("Tilapia"). Nile tilapias have the ability of regenerating their kidney if it were to get damaged in some way.

Soon after a tilapias kidney is damaged it will have a phase in which macrophages will phagocytize dead cells or other debris. After the cells and debris are cleared away the kidney will start producing signals that will initiate kidney regeneration. Those signals include myc, Pax-2, and insulin-like growth facto-1 (Reimschuessel). These signals trigger epithelial cells to migrate to the wounded spot on the kidney and start to proliferate. The cells proliferate to repopulate the basophilic epithelial basement membrane (Reimschuessel). Then the tilapia has a nephron neogenesis phase to reestablish the nephrons in the regenerated portion. The basophilic epithelium cells are used to form renal vesicles, S-shaped tubules, and tubular outgrowths which fuse with the collecting duct (Reimschuessel). The Bowman's capsule will form from the epithelial parts as well. Once all of the structures have formed the cells will stop proliferating and migrate away from the previously wounded site.

"Tilapia." *Tilapia*. Aller Aqua, 2014. Web. 28 Dec. 2014. http://aller-aqua.com/cms/front_content.php?idcat=187

Reimschuessel, Renate. "A Fish Model of Renal Regeneration and Development." *ILAR Journal* 42.4 (2001): 285-91.*Oxford Journals*. Web. 28 Dec. 2014.

http://ilarjournal.oxfordjournals.org/content/42/4/285.full

105) Pharaoh cuttlefish, Sepia pharaonis

Pharaoh cuttlefish can be found in the Indian and western Pacific Ocean (Barratt & Allcock). These cuttlefish have the ability of regenerating their arm if it was to get amputated in some way.

Soon after the arm has been amputated in some way the epidermal cells stretch and proliferate to cover the wounded area. Under the epidermis a blastema forms from undifferentiated mesenchymal cells that start to proliferate (Nair & Rao). These cells would re-differentiate into muscles and other tissues of the regenerating arm. Stem cells and blood vessels near the wound site also migrate to the arm and proliferate to rebuild it (Nair & Rao). Stem cells and cells from other specific structures would migrate as well to the regenerating arm. They would then differentiate into the suckers, chromatophores, and nervous system (Tressler et al.). All of the cells would continue to proliferate and differentiate into their respective structures until the arm had been fully regenerated. Once it was regenerated the blastema would disintegrate and the cells that were not used would disperse throughout the body.

Barratt, I. & Allcock, L. 2012. *Sepia pharaonis*. The IUCN Red List of Threatened Species. Version 2014.3. Web. 29 Dec. 2014. http://www.iucnredlist.org/details/162504/0

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DUVAUCELII ORBIGNY FROM INDUN WATERS." *Central Marine Fisheries Research Institute* 37 (1985): 160-64. *CMFRI*. Web. 29 Dec. 2014. http://eprints.cmfri.org.in/2545/1/Article_19.pdf

Tressler, Jedediah, Francis Maddox, Eli Goodwin, Zhuobin Zhang, and Nathan J. Tublitz. "Arm Regeneration in Two Species of Cuttlefish Sepia Officinalis and Sepia Pharaonis." *Invertebrate Neuroscience* 14.1 (2014): 37-49.*SpringerLink*. Web. 29 Dec. 2014. http://link.springer.com/article/10.1007%2Fs10158-013-0159-8#page-1

106) Indian squid, Loligo duvauceli

Indian squids can be found near Indian and Thailand (“Indian Squid”). These squid have the ability of regenerating their arms if any of them were to get torn off.

After the arm is severed the epithelial cells nearest the wound will proliferate and stretch to help seal the wound. A blastema will also start to from over the wound site. The blastema is comprised of undifferentiated mesenchyme, stem, epithelial, and endothelial cells (Nair & Rao). The undifferentiated mesenchyme cells will re-differentiate into the muscle and other tissues that give structural support to the newly regenerated arm. The stem cells and cells from specific structures in the body are used to recreate those specific structures in the new arm. Those structures can include the suckers, chromatophores, and nervous system (Tressler et al.). The epithelial cells will continue to proliferate and allow the arm to grow larger and longer. Finally the endothelial cells will help reestablish the blood vessels in the new arm. The cells will continue to proliferate and differentiate into the specific structures in the arm. Once the arm has been regenerated the blastema will disintegrate and the cells will migrate away from the wound and stop proliferating.

"Indian Squid." *Indian Squid: Sea Choice*. SeaChoice.org, 2013. Web. 29 Dec. 2014. http://www.seachoice.org/fish/indian-squid/

Nair, K. Prashakaran, and B. Narayana Rao. "INSTANCES OF REGENERATION IN THE CUTTLEFISH SEPIA PHARAONIS EHRENBERG AND IN THE SQUID LOLIGO

DUVAUCELII ORBIGNY FROM INDUN WATERS." *Central Marine Fisheries Research Institute* 37 (1985): 160-64. *CMFRI*. Web. 29 Dec. 2014. http://eprints.cmfri.org.in/2545/1/Article_19.pdf

Tressler, Jedediah, Francis Maddox, Eli Goodwin, Zhuobin Zhang, and Nathan J. Tublitz. "Arm Regeneration in Two Species of Cuttlefish Sepia Officinalis and Sepia Pharaonis." *Invertebrate Neuroscience* 14.1 (2014): 37-49.*SpringerLink*. Web. 29 Dec. 2014.

107) Snail fur, Hydractinia echinata

Snail fur is a colonial marine organism that attaches itself to the back of hermit crabs or similar objects (Doherty). The snail fur is made up of thousands of polyps that are all connected and help each other survive (Doherty). If one of the polyps head was to get cut or torn off another head would be regenerated.

Hydractinia have been found to have large quantities of interstitial cells in their body. These interstitial cells have the ability of differentiating into epithelial and germ cells (Plickert et al.). The interstitial cells can also activate Wnt-receptor *Frizzled* which becomes responsive to Wnt signals (Plickert et al.). The Wnt signals initiate the production of nematocytes and nerve cells in the body (Plickert et al.). It can also signal for the interstitial cells to migrate and group together near the site of a lost head. The cells will begin to proliferate and differentiate into the various structures of the head such as the nerves, tissues, and sensory receptors. Once the head has been regenerated the Wnt signaling will stop being sent, which means the cells will stop migrating and proliferating at the previously wounded spot.

Doherty, Kate. "Snail Fur: An Alternative Model Organism for Stem Cell Research." Web log post. *EuroStemCell*. EuroStemCell, 10 July 2014. Web. 30 Dec. 2014. http://www.eurostemcell.org/story/snail-fur-alternative-model-organism-stem-cell-research

Plickert, Gunter, Uri Frank, and Werner A. Muller. "Hydractinia, a Pioneering Model for Stem Cell Biology and Reprogramming Somatic Cells to Pluripotency." *The International Journal of Developmental Biology* 56 (2012): 519-34. *IJDB*. Web. 30 Dec. 2014.

108) Peacock, Pavo Cristatus

Peacocks can be found in warmer climates such as Australia, Africa, and India (“Peacock”). The males have big, long, vibrant colored feathers that they use to attract a mate, whereas females have big, long, dull colored feathers. Peacocks have the ability of regenerating their feathers after they fall off from molting or getting torn off.

Peacocks, like other birds, go through a molting cycle each year where their feathers fall off naturally and regrow, but sometimes they can be torn off and still regenerate. To regenerate their feathers the feather follicle must be formed with mesenchymal cells that form periodically arranged condensations in the dermis. The mesenchymal cells work with epithelial placodes to form the feather primordial (Yu et al.). The feather primordial differentiates and signals for the cells to proliferate and adhere together in the feather bud. The cells begin to proliferate, migrate and differentiate into the feather follicle (Yu et al.). There is an outer layer of cells that holds the feather together until the feather pops out. The middle layer and inner basal layer form the feather rachis and barbs (Yu et al.). The mesenchymal pulp is in the center and is made of fibroblasts, fibronetin, laminin, and blood vessels (Yu et al.). Once the pulp degenerates the vanes of the feather open allowing keratinocytes to flow through the dermal papilla and into the barb ridges and rachidial ridges. This creates a harden structure in the ridges. The cells in the barb ridges will then begin to differentiate into feather filaments that will be used to form the feather (Yu et al.).

"Peacock." *Peacock (Pavo Cristatus)*. A-z-animals, 2013. Web. 30 Dec. 2014.

http://a-z-animals.com/animals/peacock/

Yu, Mingke, Zhicao Yue, Ping Wu, Da-Yu Wu, Julie-Ann Mayer, Marcus Medina, Randall B. Widelitz, Ting-Xin Jiang, and Cheng-Ming Chuong. "The Developmental Biology of Feather Follicles." *International Journal of Developmental Biology* 48 (2004): 181-91. *USC Health Sciences*. Web. 30 Dec. 2014. http://www-hsc.usc.edu/~cmchuong/2004DevBiol.pdf

109) Rusty crayfish, Orconectes rusticus

Crayfish can be found in Canada and the United States in freshwater streams and lakes (Adams & Taylor). Crayfish have the ability of regenerating their claw or leg if it were to get amputated.

Soon after the limb as been amputated it undergoes a lag period in which the epithelial cells closest to the wound site proliferate and stretch to cover the wound (Hopkins). This creates a layer that encloses a blastema made from undifferentiated mesenchymal, epithelial, and endothelial cells. These cells begin to proliferate to accrue enough cells to regenerate the lost arm. Once there are enough the arm undergoes a basal growth phase (Durand; Hopkins). The mesenchyme cells begin to differentiate into muscles, tissues, and nerves of the newly regenerating arm (Durand). The epithelial cells are continually proliferating to allow the bud to grow and allow the arm to get bigger. The endothelial cells also help to reestablish blood vessels in the new leg. Once the leg has gotten big enough for the current skin it will undergo a molting cycle which removes the outer exoskeleton. This allows the crayfish to continue to grow with every successive molt by allowing water to infiltrate the newly generated exoskeleton and replace it with protein (Hopkins). Once the leg has been regenerated the blastema will disintegrate and the cells will stop proliferating. The crayfish may undergo more molts during his lifecycle but will only shed his exoskeleton which will be regenerated by epithelial cells.

Adams, S., Schuster, G.A. & Taylor, C.A. 2010. *Orconectes rusticus*. The IUCN Red List of Threatened Species. Version 2014.3. Web. 30 Dec. 2014. http://www.iucnredlist.org/details/153835/0

Durand, James B. "Limb Regeneration and Endocrine Activity in the Crayfish." *The Biological Bulletin* 118.2 (1960): 250-61. *The Biological Bulletin*. Web. 30 Dec. 2014. http://www.biolbull.org/content/118/2/250.full.pdf+html

Hopkins, Penny M. "Limb Regeneration in the Fiddler Crab, Uca Pugilator: Hormonal and Growth Factor Control."*American Zoology* 41.3 (2001): 389-98. *Integrative & Comparative Biology*. Web. 1 Jan. 2015. http://icb.oxfordjournals.org/content/41/3/389.full

110) Queen conch, Strombus gigas

Queen conch can be found in the Caribbean Sea and Gulf of Mexico (“Queen Conch”). Queen conches have the ability of regenerating their eye if it were to get amputated in some way.

Soon after the eye has been amputated from the stalk a blastema-like structure begins to develop at the tip of the stalk. The blastema houses epidermal cells near the wound site become dedifferentiated and proliferate. Some of the epidermal cells differentiate into epidermal cells that create the bilayered cornea and lens (Schwab). They also differentiate into retinular cells which are pigmented and become the photoreceptors in the eye (Schwab). As these cells are accumulated in the newly regenerating eye they will form growth cones that grow towards the optic nerve. The growth cones proliferate enough to reestablish contact with the optic nerve and allow the eye to relay its visualizations (Schwab). The retinular cells develop the retina as the epidermal cells are making the overall structure of the eye bigger. Once the eye has been regenerated the cells will stop proliferating and the blastema-like structure will disintegrate allowing the cells to disperse among the eye or body.

"Queen Conch." *Queen Conch (Strombus Gigas) - Office of Protected Resources - NOAA Fisheries*. NOAA Fisheries, 5 Nov. 2014. Web. 1 Jan. 2015. http://www.nmfs.noaa.gov/pr/species/invertebrates/queenconch.htm

Schwab, Ivan R. "Prometheus' Eye." *British Journal of Ophthalmology* 91.15 (2007): 569. *NCBI*. Web. 1 Jan. 2015.

http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1954735/

111) Eastern glass lizard, Ophisaurus ventralis

Eastern glass lizards can be found in the Southeastern states of the United States ("Eastern Glass Lizard"). They look like snakes but are indeed legless lizards. Eastern glass lizards have the ability of regenerating their tails if they were to get amputated or autotomized.

Soon after the tail has been severed from the body a wound epithelium forms over the stump from proliferated epithelial cells (Hutchins et al.). Underneath the epithelium other epithelial and endothelial cells begin to dedifferentiate and proliferate. Some of the endothelial cells form blood vessels which supply the newly regenerated epithelium with blood. The cells also differentiate into mesenchyme cells which form the ependymal from the spinal cord in the mesenchymal tissue (Alibardi). The mesenchyme cells would then re-differentiate into vascularized tissue, myofibers, cartilage tubes, and skeletal muscles (Alibardi). These would allow the tail to regenerate and grow longer. As the tail gets closer to completely regenerating the muscles would mature into myosin heavy chain positive skeletal muscles and strengthen the tail (Alibardi). Once the tail had been strengthened the cells would stop proliferating to make the tail longer and disperse away from the previously wounded area.

"Eastern Glass Lizard." *Species Profile: Eastern Glass Lizard*. Savannah River Ecology Laboratory, 2014. Web. 2 Jan. 2015. http://srelherp.uga.edu/lizards/ophven.htm

Hutchins, Elizabeth D., Glenn J. Markov, Walter L. Eckalbar, Rajani M. George, Jesse M. King, Minami A. Tokuyama, Lauren A. Geiger, Nataliya Emmert, Michael J. Ammar, April N. Allen, Ashley L. Siniard, Jason J. Corneveaux, Rebecca E. Fisher, Juli Wade, Dale F. DeNardo, J. Alan Rawls, Matthew J. Huentelman, Jeanne Wilson-Rawls, and Kenro Kusumi. "Transcriptomic Analysis of Tail Regeneration in the Lizard Anolis Carolinensis Reveals Activation of Conserved Vertebrate Developmental and Repair Mechanisms." *PLoSONE* (2014): n. pag. *PLoSONE*. Web. 2 Jan. 2015. http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0105004

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112) Star ascidian, Botryllus schlosseri

Star ascidians can be found in Atlantic Ocean down to the Mediterranean Sea (“Star Ascidian”). These sea squirts are shaped like a star and live in colonies. Star ascidians have the ability of regenerating their entire body from a single blood vessel.

Star ascidians begin to regenerate their entire body once they have been injured. Inside the blood vessel are pluripotent blood cells that proliferate and form a bud (Rinkevich et al.). A blastula forms over the bud which holds the dividing cells and allows them to differentiate. The cells begin to elongate the bud allowing folds to invaginate and form gill slits which allow the animal to breathe. Next the cells would differentiate into 3 chambers creating the central pharyngeal and pair of atrial chambers in the center of the sea squirt (Rinkevich et al.). The blastula continues to proliferate the cells and have them differentiate into the internal organs of the sea squirt. The cells finally begin to produce outgrowths that will be the zooids (Ermak). In the zooids cells will differentiate into the vasculature system and the oral siphon which allows the animal to eat. Once all of the structures in the sea squirt have been regenerated the cells will stop proliferating.

"Star Ascidian." *Star Ascidian Videos, Photos, Fact Sheet*. Wildscreen Arkive, 2014. Web. 2 Jan. 2015.
http://www.arkive.org/star-ascidian/botryllus-schlosseri/

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Ermak, Thomas H. "Botryllus & Botrylloides." *Botryllus*. Tunicarium Ascidian Microscopic Image Collection, 2011. Web. 2 Jan. 2015. http://www.tunicarium.com/Botryllus.html

113) Himalayan Newt, Tylototriton verrucosus

Himalayan newts can be found in China, India, Myanmar, Nepal, and Thailand (Peter et al.). This newt tends to live in moist forests areas and their skin can get hurt easily. The Himalayan Newt has the ability of regenerating its skin after getting bit or cut.

Tylotoin, a wound-healing-promoting peptide, has been identified in this newt that helps promote the regenerating process (Mu et al.). Once the skin has been injured it stimulates transforming growth factor beta1, interleukin 6, and cells which are essential in regenerating the injured section (Mu et al.). The needed cells migrate to the wound site and proliferate into the various structures that are needed. Keratinocytes proliferate and help regenerate the layer of skin that was damaged. The fibroblasts will then create more layers beneath the outside layer to allow the tissue to get back to its maximum size. Vascular endothelial cells also proliferate to regrow the blood vessels and nerves in the injured section of the skin. Once all of the structures have been regenerated the cells stop migrating and proliferating and disperse away from the previously injured section.

Peter Paul van Dijk, Guinevere Wogan, Michael Wai Neng Lau, Sushil Dutta, Tej Kumar Shrestha, Debjani Roy & Nguyen Quang Truong 2009. *Tylototriton verrucosus*. The IUCN Red List of Threatened Species. Version 2014.3. Web. 3 Jan. 2014. http://www.iucnredlist.org/details/59487/0

Mu, L., J. Tang, H. Liu, C. Shen, M. Rong, Z. Zhang, and R. Lai. "A Potential Wound-healing-promoting Peptide from Salamander Skin." *FASEB Journal* 28.9 (2014): 3919-929. *NCBI*. Web. 3 Jan. 2015.

http://www.ncbi.nlm.nih.gov/pubmed/24868009

114) Porcupine, Erethizon dorsatum

Porcupines can be found in Canada and the United States (“Porcupine”). They are known for throwing their sharp quills at predators to have a chance at escaping. Porcupines have the ability of regenerating their quills if they were to get torn off or thrown off in defense.

Soon after the quill has been lost or used in self-defense another quill begins to regenerate to take its place. The quill is made an outer sheath and a porous core (Yang et al.). To form the quill there are specialized epidermal cells in the epidermis of the porcupine (Yang et al.). Once the quill is lost the epidermal cells begin to proliferate to generate enough cells that will remake the quill. The epidermal cells will then differentiate into the cells that will create the outer sheath of the quill. Other cells will differentiate into the cells that create the porous foam in the middle of the quill (Taggart & Starr). As the quill gets longer more cells differentiate into the foam. Once the quill has reached its maximum size the epidermal cells will stop proliferating and differentiating until another quill is lost.

"Porcupine." *National Geographic*. National Geographic Society, 2015. Web. 3 Jan. 2015. http://animals.nationalgeographic.com/animals/mammals/porcupine/

Yang, W., C. Chao, and J. McKittrick. "Axial Compression of a Hollow Cylinder Filled with Foam: A Study of Porcupine Quills." *Acta Biomaterialia* 9 (2013): 5297-304. *Elsevier*. Web. 3 Jan. 2015.

https://www.deepdyve.com/lp/elsevier/axial-compression-of-a-hollow-cylinder-filled-with-foam-a-study-of-xqG0E4O3N5/3

Taggart, Ralph. "Principles of Anatomy and Physiology." *Biology: The Unity and Diversity of Life*. By Cecie Starr. 11th ed. Belmont: Thomas Learning, 2006. 483. Print. https://books.google.com/books?id=fb8FAAAAQBAJ&pg=PA483&lpg=PA483&dq=does+the+porcupine+epidermis+produce+quills&source=bl&ots=Oj0rErtUyL&sig=8HH9g4orqFOBL6f2LUgZr9EOqjM&hl=en&sa=X&ei=lmKyVKGtJ8S-ggS2-4LYBw&ved=0CFAQ6AEwCA#v=onepage&q=does%20the%20porcupine%20epidermis%20produce%20quills&f=false

115) Halechiniscus grevini

Halechiniscus grevini is in the Phylum Tardigrada which are water bears. They are micro-animals that can be found in the East North Atlantic Ocean and the Mediterranean Sea (Van Der Land). This creature has the ability of regenerating its sensillum, which is a filament sensory organ.

Soon after the sensillum has been amputated the hard outer honeycomb layer of the organism folds in on itself to create the joint from which the sensillum can grow from (Kristensen). Once that has been done the tormogen cells found in the basal layer of the honeycomb layer begin to proliferate and create a pocket (Kristensen). From this pocket protrudes a long structure that will make the outer layer of the sensilllum. Glial cells will also work with the tormogen cells to create a stronger, harder structure as the sensillum continues to grow and differentiate (Kristensen). Next the trichogen cells begin to proliferate and differentiate into the internal structure of the sensillum. Finally sensory cells will begin to differentiate from the cilia-supporting cells and produce the dendrites in the sensillum (Kristensen).

Van Der Land, Jacob. "Halechiniscus Greveni Renaud-Mornant & Deroux, 1976." *WoRMS - World Register of Marine Species - Halechiniscus Greveni Renaud-Mornant & Deroux, 1976*. WoRMS, 21 Dec. 2004. Web. 3 Jan. 2015. http://www.marinespecies.org/aphia.php?p=taxdetails&id=136693

Kristensen, Reinhardt Mobjerg. "Sense Organs of Two Marine Arthrotardigrades (Heterotardigrada, Tardigrada)." *Acta Zoologica* 62.1 (1981): 27-41. *Deepdyve*. Web. 3 Jan. 2015. https://www.deepdyve.com/lp/wiley/sense-organs-of-two-marine-arthrotardigrades-heterotardigrada-cDzIWZY59t/6

116) Vityazicrinus petrachenkoi

This type of sea lily can be found in the deep parts of the Central Pacific Ocean (Nakano et al.). Sea lilies have the ability of regenerating their stalk if it was to get amputated in some way.

As long as the basal plate that the old stalk used to grow from is still intact the sea lily will be able to regenerate its stalk (Eleaume et al.). The basal plate is suspected to house the undifferentiated or specialized cells needed to regenerate the stalk. Once the stalk has been lost the cells will begin to proliferate and differentiate into the specific cells needed. They differentiate into the multiple columns and crenulars in the regenerating stalk (Eleaume et al.). These columns and crenulars are connected by mutable collagenous tissue (MCT) which is collagenous fibers made from the differentiate cells as well (Eleaume et al.). In the center of the stalk is an elongated cavity lined with stereom made from specific cells from the basal plate. The cells will continue to proliferate and allow the stalk to grow taller. Once the stalk has fully regenerated the cells will stop proliferating in the basal plate.

Nakano, Hiroaki, Taku Hibino, Yuko Hara, Tatsuo Oji, and Shonan Amemiya. "Regrowth of the Stalk of the Sea Lily, Metacrinus Rotundus (Echinodermata: Crinoidea)." *Journal of Experimental Zoology Part A: Comparative Experimental Biology* 301A.6 (2004): 464-71. *Wiley Online Library*. Web. 4 Jan. 2015. http://onlinelibrary.wiley.com/doi/10.1002/jez.a.77/abstract

Eleaume, Marc, Michel Roux, and Nadia Ameziane. "A New Type of Stalk Articulation in the Sea Lily Genus Vityazicrinus (Echinodermata, Crinoidea) and Its Ontogeny." *Zoomorphology* 133 (2014): 307-20. *Deepdyve*. Web. 4 Jan. 2015. https://www.deepdyve.com/lp/springer-journals/a-new-type-of-stalk-articulation-in-the-sea-lily-genus-vityazicrinus-BHLg00EfrP/8

117) House cricket, Acheta domesticus

House crickets are native to southwestern Asia but have been spread across the world (Walker et al.). They are known for being good as bait or pets. House crickets have the ability of regenerating their leg if they were to get it torn off or damaged in some way.

Shortly after the crickets leg has been amputated the Wnt signal pathway initiates the reaction of cells surrounding the wound site (Nakamura et al.). These cells converge on the wound and form a blastema that will house the cells as they dedifferentiate and proliferate to regenerate the leg. First the cells will differentiate into epidermal cells that will form the exoskeleton of the cricket's leg. These will actively proliferate, allowing the leg to get larger as it grows. Then the cells will differentiate into chondrocytes that will form the cartilage in the joint and the muscles in the rest of the leg. Finally endothelial cells will differentiate and form the blood vessels and nerves in the leg. Three other signals have been found to initiate and regulate the proliferation and differentiation of the cells in the blastema. Those signals are the Hh, Dpp, and Wg signals. The Hh signal organizes the leg growth and patterning (Nakamura et al.). The Dpp signal differentiates the cells into chondroctyes while Wg signals the formation of the distal leg portions (Nakamura et al.). Once the leg has been completely regenerated the blastema will disappear and the cells will stop proliferating.

Walker, Thomas J., Paul M. Choate, and Don Wasik. "Common Name: House Cricket." *House Cricket - Acheta Domesticus (Linnaeus)*. University of Florida, Jan. 1999. Web. 5 Jan. 2015. http://entnemdept.ufl.edu/creatures/misc/crickets/adomest.html

Nakamura, T., T. Mito, T. Bando, H. Ohuchi, and S. Noji. "Dissecting Insect Leg Regeneration through RNA Interference."*Cellular and Molecular Life Sciences* 65 (2008): 64-72. *Deepdyve*. Web. 5 Jan. 2015. https://www.deepdyve.com/lp/springer-journals/molecular-and-cellular-basis-of-regeneration-and-tissue-repair-nZIobAHySr/3

118) Shark, Leonodus carlsi

This type of shark lived in the Devonian age but are similar to more primitive sharks. Sharks are able to go through 7-12 sets of teeth each year and are replaced by new teeth waiting in the back of the mouth ("Sharks, Stingrays and Skates"). Once the teeth have been lost new teeth will take its place through regeneration.

The sharks jaw has a dental lamina which houses special cells for creating teeth. These cells are continuously proliferating and creating tooth buds. These tooth buds enlarge and then poke out of the lamina (Botella et al.). As more teeth are made previously generated teeth are pushed to the jaw margin (Botella et al.). At this point the teeth wait until they can replace any tooth like in a 'conveyor belt' system (Botella et al.). More research is being done to learn what the special cells are and how they are activated continuously.

"Sharks, Stingrays and Skates." *New Zealand Sharks*. National Aquarium of New Zealand, 2014. Web. 6 Jan. 2015. http://www.nationalaquarium.co.nz/animals-and-fish/new-zealand-animals-and-fish/sharks/

Botella, Hector, Jose I. Valenzuela-Rios, and Carlos Martinez-Perez. "Tooth Replacement Rates in Early Chondrichthyans: A Qualitative Approach." *Lethaia* 42 (2009): 365-76. *Deepdyve*. Web. 6 Jan. 2015. https://www.deepdyve.com/lp/wiley/tooth-replacement-rates-in-early-chondrichthyans-a-qualitative-W5qeumfJrd/1

119) Chicken, Gallus gallus domesticus

Chickens can be found all over the world and are used for their meat and eggs. Avian chicks have been found to have the ability of regenerating their spinal cord while in the embryo if it was damaged in some way.

Soon after the spinal cord has been cut or damaged specialized cells migrate to the wound site and begin to proliferate. These cells include astrocytes, Schwann cells, and oligodendrocytes (Keirstead et al.). Astrocytes proliferate and differentiate into the glial cells that make up the neurons in the spinal cord. More astrocytes proliferate to create a connection from both sides of the wounded area. The Schwann cells create the myelin sheath around the neurons in the peripheral nervous system. Oligodendrocytes create myelin sheath around the neurons in the central nervous system (Keirstead et al.). Once the connection has been made across the gap and the myelin sheath has been added the cells will stop proliferating and migrate away from the wounded site.

Keirstead, Hans S., Jason K. Dyer, Gerald N. Sholomenko, John McGraw, Kerry R. Delaney, and John D. Steeves. "Axonal Regeneration and Physiological Activity Following Transection and Immunological Disruption of Myelin within the Hatchling Chick Spinal Cord." *The Journal of Neuroscience* 15.10 (1995): 6963-974. *The Journal of Neuroscience*. Web. 6 Jan. 2015. http://www.jneurosci.org/content/15/10/6963.long

120) Eastern (Red-spotted) newt, Notophthalmus viridescens

Eastern newts are commonly found on the eastern side of the United States near water sources or damp forests (“Eastern/Red-spotted Newt”). Red-spotted newts have the capacity of regenerating their knee joints.

Soon after the joint has been damaged cells surrounding the wound undergo aptosis and this initiates local and specialized proteins to migrate to the wound site. The matricellular proteins, such as TN-C, DCN, POSTN, and SPARC, are all upregulated in the joint (Susanto). These specific proteins help control the regeneration process. SPARC was shown to initiate regeneration and muscle formation in the joint (Susanto). TN-C would then initiate the muscle to form and mature (--). POSTN and DCN help the development of collagen which creates the muscle in the joint and the tendons around the bone (Susanto). The proteins would continue to proliferate until the joint had been completely reformed. Once that happened the proteins would stop being signaled and stop proliferating.

"Eastern/Red-spotted Newt." *Eastern Red-spotted Newt*. New Hampshire Fish and Game, 2014. Web. 7 Jan. 2015. http://www.wildlife.state.nh.us/Wildlife/Nongame/salamanders/east-redspot_newt.htm

Susanto, Sony Adhi. "Joint Regeneration Mechanisms in Red-spotted Newts (Notophthalmus Viridescens Viridescens)." Diss. Justus-Liebig-U of Giessen, 2014. *Joint Regeneration*

Mechanisms in Red-spotted Newts (Notophthalmus Viridescens Viridescens). GEB - Giessen Electronic Library, 21 Aug. 2014. Web. 7 Jan. 2015. http://geb.uni-giessen.de/geb/volltexte/2014/10997/pdf/SusantoSonyAdhi_2014_07_24.pdf

121) California sea hare, Aplysia californica

California sea hares can be found on the coast of California and Mexico (Dice). These creatures are soft bodied animals that can get hurt easily. The California sea hare has the ability of neural regeneration if it were to get hurt in some way.

Soon after the spinal cord is crushed or cut certain neurotransmitters help initiate the regeneration. Those neurotransmitters include serotonin, calcitonin, L-glutamatem, and somatostatin (Moffett). These transmitters can create a more suitable environment for the neurons to regenerate or they help stimulate the ganglia regeneration. The ganglia are formed by neurosecretory cells that proliferate and differentiate into the specific structures (Moffett). Nerve growth factor has been found to help initiate nerve growth as well in some snails. It stimulates non-specialized cells to differentiate into the neurites. Next fibronectin is stimulated to proliferate and form the connective tissue sheath of the ganglia (Moffett). Finally laminin, which is an extracellular matrix protein, helps promote the outgrowth of the neurons so they can connect with other neurons and complete the neural regeneration (Moffett).

Dice, Samantha. "Aplysia Californica." *ADW: Aplysia Californica*. Animal Diversity Web, 5 Sept. 2014. Web. 7 Jan. 2015. http://animaldiversity.org/accounts/Aplysia_californica/

Moffett, Stacia B. "Neural Regeneration in Gastropod Molluscs." *Progress in Neurobiology*46 (1995): 289-330. *Deepdyve*. Web. 7 Jan. 2015.

https://www.deepdyve.com/lp/elsevier/neural-regeneration-in-gastropod-molluscs-0xI0Wvdzhh/31

122) Coral, Fungia granulosa

Fungia granulosa is a type of coral that lives in the Indian and Pacific Oceans (Hoeksema et al.). Global climate change and predation has become a major issue for coral. If this coral was to have its tissue injured it could undergo regeneration and fix it.

Once coral are injured they must regenerate their tissue fast enough before algae and other sediments get in the wound. If algae and other sediments get in the wound it will cease the regeneration process and could kill the coral. The coral regenerates by first clearing away all of the debris and dead/damaged cells near the wound site with microdermabrasions (Kramarsky-Winter & Lova). Once they are cleared away the stem cells begin to proliferate and migrate to the wound site. As more are added and join together it creates a layer of tissue that covers the bare skeleton. The stem cells continue to differentiate into tissue layers below the outer layer to allow the coral to regenerate its full tissue size (Kramarsky-Winter & Lova). Once it has grown back its maximum size the tissue will mature and become pigmented. After that has occurred the stem cells will stop proliferating to regenerate the injured tissue and will go back to proliferating and differentiating into oocytes (Kramarsky-Winter & Lova).

Hoeksema, B.W., Wood, E., Rogers, A. & Quibilan, M.C. 2014. *Fungia granulosa*. The IUCN Red List of Threatened Species. Version 2014.3. Web. 7 Jan. 2015. http://www.iucnredlist.org/details/133183/0

Kramarsky-Winter, E., and Y. Loya. "Tissue Regeneration in the Coral Fungia Granulosa: The Effect of Extrinsic and Intrinsic Factors." *Marine Biology* 137 (2000): 867-73.*Deepdyve*. Web. 8 Jan. 2015. https://www.deepdyve.com/lp/springer-journals/tissue-regeneration-in-the-coral-fungia-granulosa-the-effect-of-RmLC7M5V0L/6

123) Black-ball sponge, Ircinia strobilina

Black-ball sponges can be found on reefs near Florida to the Guyana shelf (De Kluijver et al.). These sponges have the ability of regenerating a section of their body if it were to get cut or bit off.

This sponge goes through three phases of regeneration after getting injured in some way. The first phase includes cells closest to the wound proliferating and joining together to form a layer of ectosome tissue (Hoppe). This layer is thin and covers the wound to allow the tissue to completely regenerate. The next phase was to have those cells mature to give off a normal texture and color. Finally the cells would continue to proliferate and create more layers beneath the ectosome tissue (Hoppe). This would allow that area in the sponge to grow back to its normal size. Once the area has been completely regenerated the cells will stop proliferating and disperse away from the previously wounded area.

De Kluijver, M., G. Gijswijt, R. De Leon, and I. Da Cunda. "Black-ball Sponge (Ircinia Strobilina)."*Marine Species Identification Portal : Black-ball Sponge - Ircinia Strobilina*. Key to Nature, 2014. Web. 7 Jan. 2015. http://species-identification.org/species.php?species_group=caribbean_diving_guide&id=456

Hoppe, Wilfried F. "Growth, Regeneration and Predation in Three Species of Large Coral Reef Sponges." *Marine Ecology Progress Series* 50 (1988): 117-25. *Inter-Research Science Center*. Web. 8 Jan. 2015.

http://www.int-res.com/articles/meps/50/m050p117.pdf

Repair

1) General wound healing

If an animal gets a cut on their arm and does not have regeneration abilities, the wound will heal and most likely become scar tissue. Immediately after it gets cut the wound will start bleeding and as long as there is not a bleeding disorder the blood will clot. This clot has fibrin, which allows the clot to stay in place as it dries (Harding et al.). Once clotted the blood vessels dilate to allow blood-oxygen, nutrients, and innate immune response to occur. Neutrophils converge on the wound site to phagocytize any viral or bacterial infection that may occur (Harding et al.). Basophils provoke acute inflammation at the sites where antigens were deposited from the bacteria or virus. Basophils release histamine, which causes the inflammation and macrophages process the antigen for the lymphocytes. Langerhans cells, skin cell macrophages, phagocytize damaged or dying neutrophils and stimulate interleukin-1. Interleukin-1 increases body temperature, stimulates T-lymphocytes, and stimulates fibroblasts. Fibroblasts secrete extracellular matrix precursors and collagen proteins that form connective tissues (Mandal). If the cut was deep the fibroblasts will produce immature collagen, which have less tensile strength than proper collagen. This in turn causes a scar to appear.

Mandal, Ananya. "What Are Fibroblasts?" *What Are Fibroblasts?* News-medical.net, 06 May 2010. Web. 14 Jan. 2015. http://www.news-medical.net/health/Fibroblasts-What-are-Fibroblasts.aspx

Harding, K. G., H. L. Morris, and G. K. Patel. "Healing Chronic Wounds." *British Medical Journal* 324.7330 (2002): 160-63. *NCBI*. Web. 14 Jan. 2015.

http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1122073/

2) Skin Grafts, same individual

If humans were to get burned they could receive a split thickness skin graft (STSG) as an autograft. The grafted skin from the donor section leaves behind the adnexal remnants so that epidermal cells can proliferate and create the lost tissue in the donor site (Daller). This site will be stitched together by the surgeon and over time epithelial cells will proliferate and replenish the lost tissue. The recipient section has the adnexal remnants and only needs the epidermis and dermis ("Chapter 2"). The surgeon will stitch the STSG into the recipient sections. The endothelial cells from the recipient donor will proliferate and connect the blood vessels from the recipient to the donated graft. Once the blood vessels are established epithelial cells can start to proliferate and fill in the gaps between the recipient and donor skin pieces.

"Chapter 2." *Plastic Surgery Essentials for Students*. 8th ed. Arlington Heights: American Society of Plastic Surgeons, 2012. 9-15. *Plastic Surgery Essentials for Students*. American Society of Plastic Surgeons, 2012. Web. 1 Jan. 2015. http://www.plasticsurgery.org/Documents/medical-professionals/publications/Essentials-Chapter-2-Grafts-and-Flaps.pdf\

Daller, John A. "Skin Graft." *Skin Graft: Medline Plus*. U.S. National Library of Medicine, 1 Jan. 2013. Web. 17 Jan. 2015. http://www.nlm.nih.gov/medlineplus/ency/article/002982.htm

3) Transplants, already formed

Humans are prone to having an organ failing or damaged which means they need a organ transplant or they will die. The first step is to find a suitable donor which can be challenging because they need to have similar chemical characteristics as the recipient or they will reject it ("Organ Transplantation"). Once they find a donor they will surgically remove the organ from the donor and surgically place it into the recipient. Once they have attached the new organ into place they will stitch up the incision and allow epithelial cells to proliferate and heal the wound. After the procedure the recipient will have to take prescription drugs for the rest of their life to ensure that the body will not reject the new organ ("Organ Transplantation").

"Organ Transplantation." *Organ Transplantation: Medline Plus*. U.S. National Library of Medicine, 26 Nov. 2014. Web. 18 Jan. 2015. http://www.nlm.nih.gov/medlineplus/organtransplantation.html

4) Transplants, in vitro

As humans get older parts of the body are prone to get damaged or fail, but there are also some very young kids who organs are not useful. To help the individual survive they can undergo transplant surgery and use an organ that was grown in vitro with the recipients own cells (Halley). For example, a scientist can take cells from your bladder and place them in a culture for five to seven weeks around a biodegradable scaffold (Halley). Once the bladder is ready to be placed in the body the surgeon can make an incision and place the bladder in its rightful place. They will remove the old bladder as well to make more room for the new one. Then they will suture the organ to the veins and arteries and allow the endothelial cells to proliferate and make a more permanent connection. The surgeon will then stitch the incision site closed and allow the epithelial cells to proliferate and heal the wound. After the bladder has been in the body for a while the biodegradable scaffold will degrade leaving the bladder to adapt to the environment.

Halley, Drew. "Growing Organs in the Lab." *Growing Organs in the Lab: Singularity Hub*. Singularity University, 8 June 2009. Web. 20 Jan. 2015. http://singularityhub.com/2009/06/08/growing-organs-in-the-lab/

5) Transplant, 3D printing

In the more recent years scientists have been working with computer scientists to engineer something that can create an organ that can be used in the body. They have engineered a printer that can print 3D tissues using cells (O'Toole). First they grow human cells in vitro from biopsies or stem cells. Then they feed the cells into the printer that can take the cells and arrange them in a specific order based on the cell type. As more are added the structure will start forming into a 3D shaped structure looking like a human generated organ. Then the cells signal to each to fuse together so they can create a more fluid, communicative system. Since this project is still in the first years of its invention there have not been any substantial experiments with transplanting the 3D structure into a being. Although next year scientists believe that they will finally be able to give someone a 3D printed organ transplant ("World's First 3D-bioprinted Transplant-ready Organ"). Once they are available the recipient will undergo surgery to insert the organ into place.

O'Toole, James. "3-D-printed Organs Are on the Way." *CNNMoney*. Cable News Network, 4 Nov. 2014. Web. 20 Jan. 2015. http://money.cnn.com/2014/11/04/technology/innovationnation/3d-printed-organs/

"World's First 3D-bioprinted Transplant-ready Organ to Be Unveiled in Early 2015." *World's First 3D-bioprinted Transplant-ready Organ to Be Unveiled in Early 2015*. RT News, 4 Nov. 2014. Web. 20 Jan. 2015. http://rt.com/news/202175-3d-bioprinted-organ-transplant/

6) Ear piercing

Many people have their ears pierced and sometimes multiple piercings. Most people do it because it adds beauty others do it for cultural or religious beliefs. Once the ear is pierced it undergoes a healing process that can be divided into three phases: inflammatory, proliferative, and maturation (Kancheska et al.). The inflammatory phase happens the first days after piercing the ear. It involves the injured site becoming swollen and tender and sending signals for neutrophils to migrate to the wound. Next is phase the proliferative phase in which epitheliazation and angiogenesis occurs. Epitheliazation warrants the proliferation of epithelial cells that create the new skin that covers the wound all around the ear piercing. Angiogenesis occurs when endothelial cells proliferate and create precursors for blood vessels and connect them to old blood vessels. Finally the pierced ear undergoes maturation which involves the epithelial turning into keratin and endothelial cells maturing into blood vessels. The pierced ear should be healed and not bleed if you were to remove the earing.

Kancheska, Iva, Matt Griffith, and Brian Stewart. "Body Piercing - Healing Phases." *Body Piercing - Healing Phases*. Skin Artists, 2014. Web. 6 Jan. 2015. http://www.skin-artists.com/body-piercing-healing-phases.htm

7) Tattoos

Many people get tattoos all over their bodies because it adds artistic appeal to their body or cultural and religious beliefs. Tattoos are made by a needle puncturing the skin and injecting ink into the dermis layer under the epidermis (skin) (Geranyl). Soon after the skin has been punctured there is an inflammatory response to heal the wound. Neutrophils, macrophages, keratinocytes, and fibroblasts swarm to the injured site to phagocytize the debris and heal the epidermis (Geranyl). The macrophages try to destroy the ink but the particles are too big for it to digest which stops the macrophages from dispersing since it has not clear the contaminant. This results in fibroblasts migrating around the macrophages and proliferating to form the collagen to build the tissue of the skin. Keratinocytes acquire some of the ink as well which means that when they proliferate the ink will permanently stay in the epidermis and be visible to the eye (Geranyl).

Geranyl. "Tattoo Ink - Where Does It All Go." *Tattoo Ink - Where Does It All Go*. The Evergreen State College, 13 Jan. 2003. Web. 8 Jan. 2015. http://archives.evergreen.edu/webpages/curricular/1999-2000/humanbio/TattooInk.htm

8) Common Hippopotamus, Hippopotamus amphibius

Hippopotami are found in Africa near rivers or other sources of water. They are currently marked as 'Vulnerable' on the International Union for Conservation of Nature and Natural Resources threatened species list (Lewison). Hippopotami are capable of producing a blood-sweat sunscreen that has multiple functions such as a sunscreen, antibiotic, and coolant. The blood sweat has been identified as two chemical compositions termed: hipposudoric acid and norhipposudoric acid (Hopkin). The two acids mixed together help protect the skin from the harmful UV rays so the hippo doesn't get cancer. It has also been found that the hipposudoric acid has the ability to restrict the growth of Pseudomonas aeruginosa and Klebsiella pneumonia. The restrictive properties has not been fully researched but they are sure hipposudoric acid has that property.

Lewison, R. & Oliver, W. (IUCN SSC Hippo Specialist Subgroup) 2008. *Hippopotamus amphibius*. The IUCN Red List of Threatened Species. Version 2014.3. Web. 21 Jan. 2015. http://www.iucnredlist.org/details/10103/0

Hopkin, Michael. "Hippos Beat the Burn." *Hippos Beat the Burn: Nature.com*. Nature Publishing Group, 27 May 2004. Web. 10 Jan. 2015. http://www.nature.com/news/2004/040527/full/news040524-7.html

9) Wood frog, *Lithobates* (*Rana*) *sylvaticus*

Wood frogs can be found in the United States but are primarily found in Alaska. The temperatures can range from a minimum of -18.1 to average -6.3 degrees Celsius for around 193 consecutive days from October to May (Larson et al.). Wood frogs have the remarkable ability of freezing themselves during the winter and then unthawing during the summer months to survive.

As the temperature outside gets colder the frog will find a place to undergo its natural hibernacula. The frog will surround and cover itself with dirt and leaves to help insulate its body. Then slowly the body organs begin to shut-off, but not die so they can essentially 'come back to life' once the warmer weather comes back. Wood frogs have high freezing tolerances due to the presence of cryoprotectants: low molecular mass and high molecular mass xylomannan-based antifreeze glycolipid (AFGL) (Larson et al.). AFGL is present on the cell membranes and prevents the extracellular ice from crossing into the cytoplasm and killing the still living and functional cells (Larson et al.). Urea and glucose have also been found to help retain water inside the tissues so the frog will have enough liquid to live after unthawing process (Larson et al.). Since the frogs live in a cycle where there are many stages of freezing and unthawing, the frog's glycogen is converted to glucose and then stored in the tissues (Larson et al.). Consecutive cycles would account for a build of glycogen in the tissues which has been found to increase the frogs tolerance of cold. This means the frog can still survive if the temperature drops below the normal low temperatures or if the winter lasts for longer than expected. As the temperatures begin to increase the frog unthaws and the unfrozen cells begin to signal for the rest of the organs to start functioning again.

Larson, Don J., Luke Middle, Henry Vu, Wenhui Zhang, Anthony S. Serianni, John Duman, and Brian M. Barnes. "Wood Frog Adaptations to Overwintering in Alaska: New Limits to Freezing Tolerance." *The Journal of Experimental Biology* 217 (2014): 2193-200. *The Journal of Experimental Biology*. Web. 13 Jan. 2015. http://jeb.biologists.org/content/217/12/2193.long

10) Skin graft, allograft

Humans can sustain intense burns and need skin grafts to cover the wound. While they are waiting for the autograft from the recipients skin to use as treatment they can use an allograft. An allograft is tissue that is removed from one individual and used on a different individual (“Skin Banking”). They normally use skin from cadaveric donors for the allograft. The doctor, coroner, or autopsy personnel removes the skin off of the cadaver and freezes it in cryoprotectants for up to 5 years until someone needs the skin (“Skin Banking”). They can also take the skin and immediately place it on the recipient after it has been released from quarantine which can last up to 10 days. The surgeons stitch it on the recipient as a protective barrier from infection and fluid loss, and promote underlying tissue to heal, but it will be rejected within 7-21 days (“Skin Banking”). That is why it is just a temporary fix until the autograft is available to be sewn on.

"Skin Banking." *University of Michigan Trauma Burn Center*. Regents of the University of Michigan, 2014. Web. 13 Jan. 2015. http://www.traumaburn.org/who/skinbank/banking.shtml

11) Skin graft, xenograft

Humans can sustain injuries to the skin or organs and to help heal or cover that wound surgeons can use xenograft transplantation. Xenografts are the transmission of living tissues or cells from one species to another (Trice). They are keen on using pigs as the tissue and organ donors, but they are also using bovine and equine sources. The doctor removes the tissue from the animal and places it over the wound. Then he/she will stitch it on to keep it in place and allow the epithelial and endothelial cells to proliferate and heal the wound. The doctor can also take an organ from the animal and place it in the body. Then they reconnect it by suturing it to the blood sources and allowing the endothelial cells to form a more permanent connection. The surgeon will then stitch up the incision and allow the epithelial cells to proliferate and heal it.

Trice, Michael E. "Xenograft Risks: What You and Your Patients Need to Know." *American Academy of Orthopaedic Surgeons* 9.1 (2009): n. pag.*AAOS*. Web. 15 Jan. 2015. http://www.aaos.org/news/aaosnow/jun09/research3.asp

12) Human, Homo sapiens

Humans have the ability of healing after getting burned. The healing process includes reactive, reparative, and remodeling steps. The reactive step is the inflammatory response that happens immediately after getting burned (Tiwari). At first there is local vasodilatation which causes the blood vessels to widen. This effect allows fluid to escape which if too much fluid is lost due to increased capillary permeability the individual could go into shock. Neutrophils, monocytes, and macrophages are also able to migrate to the wound to phagocytize the dead tissue and toxins released by the burned tissue (Tiwari). Next comes the reparative step which helps recreate the epidermis. In partial thickness burns which only takes the top layer of the skin off, keratinocytes migrate to the wound site and start to proliferate (Tiwari). After much proliferation the cells reform the epidermis and allow for that layer to continue producing more epithelial cells long after the wound has completely healed. In deep dermal burns surgeon would use a graft and use it as the new epidermis so there would be no need for the reparative phase. Finally in the remodeling phase the wound is further stabilized by collagen and elastin forming around the epithelial, endothelial, and smooth muscles that were formed creating an extracellular matrix (ECM) (Tiwari). This ECM would later turn into scar tissue and myofibroblasts which contract the scar (Tiwari). In deep dermal burns this phase could take years to become fully complete.

Tiwari, V. K. "Burn Wound: How It Differs from Other Wounds?" *Indian Journal of Plastic Surgery* 45.2 (2012): 364-73. *NCBI*. Web. 15 Jan. 2015. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3495387/

13) Bioengineered skin grafts for venous leg and diabetic foot ulcers

Humans can get ulcers on their legs and feet that don't heal properly. Scientists have designed bilayered bioengineered skin substitute (BBSS) to replace the ulcers and prevent problems (Curran & Plosker). One type of bioengineered skin is Aligraf which uses neonatal foreskin keratinocytes and fibroblasts, while in a bovine type 1 collagen matrix (Curran & Plosker). The keratinocytes and fibroblasts are stored in cryopreservation vials to be used later. When the time comes for their use keratinocytes are proliferated and differentiate into the epidermal layer in the same culture that the fibroblasts are proliferating differentiating into the dermal layer. These layers are later incubated which produces a stratum corneum and makes the complete skin graft ("How Is It Made?"). It has been found that BBSS does not produce antigen-presenting cells which allows the recipients body to have a better chance of not rejecting the skin graft (Curran & Plosker). Once the skin has been put in place on the recipient the surgeons stitch it on and place a dressing over it. Blood vessels will also form from endothelial cells given off by the recipients mesoderm. This allows for the grafted skin to receive blood. Over time the epithelial cells in the epidermis proliferate and fill in the space between the recipients skin and the grafted skin.

Curran, M. P., and G. L. Plosker. "Bilayered Bioengineered Skin Substitute (Apligraf): A Review of Its Use in the Treatment of Venous Leg Ulcers and Diabetic Foot Ulcers." *BioDrugs* 16.6 (2002): 439-55. *NCBI*. Web. 15 Jan. 2015. http://www.ncbi.nlm.nih.gov/pubmed/12463767

"How Is It Made?" *Apligraf: How Is It Made?* Apligraf, 2010. Web. 16 Jan. 2015.

http://www.apligraf.com/professional/what_is_apligraf/how_is_it_made/

14) Sewing finger or toe back on

Humans can have accidents that lead to a finger or toe getting cut off. Surgeons are able to use microsurgery to reattach the finger or toe if the digit can be saved. In this surgery the doctor uses thread and needles so small that microscopes and needle nosed jeweler's forceps are used instead of regular needles and thread ("Microsurgery: Your Guide to Recovery"). The surgeon reconnects the arteries and veins still in the hand or foot to the arteries and veins in the digit as their main priority so the digit won't die. Their other priority is to set the bones back together as best as possible so it can go through the healing process. They also try to reconnect tendons and soft tissue to better help the digit survive and improve its function ("Microsurgery: Sewing Blood Vessels and Nerves Back Together"). Once the inner workings of the digit have been reconnected the surgeon will use regular needle and thread to stitch the epidermis of the hand or foot to the digit that was lost. Over time the wound will heal by cells in the epidermis proliferating and forming new skin layers that attach the two pieces together. Once the wound has healed there will be a noticeable fibrous scar instead of fully regenerative skin.

"Microsurgery: Your Guide to Recovery." *Microsurgery: Your Guide to Recovery*. California Pacific Medical Center, 3 Dec. 2014. Web. 17 Jan. 2015. http://www.cpmc.org/learning/documents/microsurgery.html#What is Microsurgery?

"Microsurgery: Sewing Blood Vessels and Nerves Back Together :: Health Medicine." *Microsurgery: Sewing Blood Vessels and Nerves Back Together :: Health Medicine*. 123HelpMe.com, 2014. Web. 17 Jan. 2015.

http://www.123helpme.com/view.asp?id=23915

15) stents

All mammals have arteries that allow blood to flow to the heart. If one of those arteries is clogged with plaque or is too narrow problems can arise for that mammal. A stent is a small mesh tube that is placed inside of an artery to strengthen or widen it so the problems can be fixed and/or prevented ("What Is a Stent?"). To place the stent in an artery, a doctor will cut a small opening in a blood vessel in the groin, arm or neck. Through the opening they insert a thin catheter that has a stent placed around a deflated balloon ("How Are Stents Placed?"). The doctor will move the catheter through your body to the artery of concern by looking through a special x-ray machine. If the artery is full of plaque the doctor will inflate the balloon allowing the blood pressure to push the plaque out of the way ("How Are Stents Placed?"). The inflation will also allow the stent to expand and push into the artery into place. Once the stent is in place the balloon will be deflated and the doctor will remove the catheter the way it came in. The incision where the catheter was inserted into the body is so small that the doctors just bandage it up and you don't need stitches. The blood from the injured site will clot and over time the epithelial cells in the epidermis will proliferate and cover the small incision leaving no visible traces that there was a cut.

"What Is a Stent?" *What Is a Stent? - NHLBI, NIH*. National Heart, Lung, and Blood Institute, 17 Dec. 2013. Web. 18 Jan. 2015.
http://www.nhlbi.nih.gov/health/health-topics/topics/stents

"How Are Stents Placed?" *How Are Stents Placed? - NHLBI, NIH*. National Heart, Lung, and Blood Institute, 17 Dec. 2013. Web. 18 Jan. 2015. http://www.nhlbi.nih.gov/health/health-topics/topics/stents/placed

"What To Expect After a Stent Procedure?" *What To Expect After a Stent Procedure? - NHLBI, NIH*. National Heart, Lung, and Blood Institute, 17 Dec. 2013. Web. 18 Jan. 2015. http://www.nhlbi.nih.gov/health/health-topics/topics/stents/after

16) North American Opossum, Didelphia virginiana

The North American Opossum can be found all over the United States, primarily in the southern states, and Mexico. This is the only marsupial in the United States and has babies as tiny as honeybees which ride in their mothers' pouch ("Opossum", 2015). The Opossum has been found to be immune to the venom of snakes.

One key reason Opossums are immune to venoms of various different snakes is the Lethal Toxin Neutralizing Factor (LTNF) protein (Lipps, B.V. 1999). This protein is a naturally occurring protein in the Opossums body. Once the snake has bitten the Opossum this protein is activated to proliferate. The protein will attach to the venom because it has a high binding affinity to the venom (Lipps, B.V. & Lipps, F.W. 1998). LTNF will then neutralize the venom by a means that is not completely understood; it ultimately turns the venom into a compound that can be digested and is not harmful.

"Opossum." *National Geographic*. National Geographic Society, 2015. Web. Retrieved February 20, 2015, from http://animals.nationalgeographic.com/animals/mammals/opossum/.

LIPPS, B. V.. (1999). ANTI-LETHAL FACTOR FROM OPOSSUM SERUM IS A POTENT ANTIDOTE FOR ANIMAL, PLANT AND BACTERIAL TOXINS. *Journal of Venomous Animals and Toxins*, *5*(1), 56-66. Retrieved February 20, 2015, from http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0104-79301999000100005&lng=en&tlng=en. 10.1590/S0104-79301999000100005.

Lipps, B.V. & Lipps, F.W. (April 28, 1998). Lethal toxin neutralizing factors. Google Patents. Retrieved February 20, 2015, from http://www.google.com/patents/US5744449.

17) Vibrio cholerae

Water can become contaminated with the bacterium Vibrio cholerae. Once the individual ingests the bacteria it will colonize in the intestines (University of York.). It is able to survive in the intestines by eating the sialic acid sugars on the surface of the gut cells (University of York.). As it proliferates into many bacterium it is able to secrete a toxin which causes havoc in the body. The major problem is diarrhea because if left untreated the individual could become severely dehydrated and lose a lot of its vitamins and minerals leading to death. Once the body has been infected with the bacterium the innate immune response will be triggered allowing natural defense mechanisms to converge on the bacterium and slow or hinder the proliferation (Rollwagen, Florence M). The acquired immune response will then be triggered and release Immunoglobulin A antibodies which bind to the bacteria signaling to the macrophages what to destroy (Rollwagen, Florence M). The immune system along with fluids will allow the individual to recover.

University of York. "University of York Scientists Reveal How Cholera Attacks Body." *News-Medical.net*. News Medical, 30 Jan. 2012. Web. Retrieved March 5, 2015, from http://www.news-medical.net/news/20120130/University-of-York-scientists-reveal-how-cholera-attacks-body.aspx.

Rollwagen, Florence M. "Immune System Response Agaisnt Cholera." AE Biology. All Experts, 24 May 2009. Web. Retrieved March 4, 2015, from http://en.allexperts.com/q/Biology-664/2009/5/Immune-system-response-against.htm.

18) Salmonella

Eating raw or undercooked meat, poultry, or poultry products can allow an individual to become infected with the bacteria salmonella (Koerth, Maggie). Salmonella will reside in the intestines and proliferates over a certain amount days until there are enough to launch an attack on the intestines. Once they have the numbers the bacteria will release proteins and toxins that target the intestinal cells (Koerth, Maggie). The toxins break down the intestinal cells causing pain, diarrhea, and bloody stool (Koerth, Maggie). The body starts responding as soon as the bacteria gets to the intestines by creating a competitive environment with the other bacteria. If that doesn't work then paneth cells start producing antimicrobial peptides which help deter the bacteria from reproducing (Oram, Brian.). The acquired immune system will then kick in and create antibodies helping the macrophages destroy the bacteria. If that still does not work then the gut will release an enzyme which alters the structure of the salmonella Fe+ binding protein Ent, which stops it from reproducing (Oram, Brian.).

Koerth, Maggie. "Salmonella's Tricky Attack Plan Revealed." LiveScience. TechMedia Network, 19 June 2008. Web. Retrieved March 2, 2015, from http://www.livescience.com/2629-salmonella-tricky-attack-plan-revealed.html.

Oram, Brian. "Corrosion Is a Complex Series of Reactions between the Water and Metal Surfaces and Materials in Which the Water Is Stored or Transported." *Drinking Water Corrosion, Corrosivity, Saturation Index, Corrosion Treatment, Corrosion Management,*

Materials Engineering Training. Water Research Center, 2014. Web. Retrieved March 2, 2015, from http://www.water-research.net/index.php/drinking-water-issues-corrosive-water-lead-copper-aluminum-zinc-and-more

2) Prosthetics

Mammals are known for having accidents and some times they can be so serious that they lose an arm, leg, or hand. Unfortunately reconnecting one of those missing parts and regeneration of body parts has not been completely investigated to where they are viable options. The next choice is to get a prosthetic limb. A prosthetic is a device designed out of variable materials to replace the missing body part (Vorvick). The prosthetic device is attached to the stump of the lost limb by a suspension system. The suspension system usually uses harnesses, straps, belts, or sleeves to fit on the stump (Clements). Although they can also use a suction mechanism to attach the prosthetic which helps it fit more comfortably and stay on tight.

Vorvick, Linda J. "Prosthesis." *Medline Plus*. U.S. National Library of Medicine, 21 Jan. 2013. Web. 12 Jan. 2015. http://www.nlm.nih.gov/medlineplus/ency/article/002286.htm

Clements, Isaac Perry. "How Prosthetic Limbs Work." *Modern Prosthetic Limbs*. HowStuffWorks.com, 2014. Web. 12 Jan. 2015. http://science.howstuffworks.com/prosthetic-limb2.htm

3) Wheelchairs

Humans have unfortunately been prone to getting their legs or spinal cord injured or diseased. This can cause the inability to use their legs, which can make life very hard for that human. Instead of having to drag their legs behind them as they crawl on their hands the human can be fitted for a wheelchair. There are various forms of wheelchairs that can fit various humans. One example is the non-powered wheelchair which is a leather/vinyl seat with arm rests and two large wheels on the side to roll. The individual in the seat has the option of pushing himself/herself by turning the wheels or having someone push them from handlebars sticking out the back. Another example is the powered wheelchair that has a plush, cushioned seat with cushioned armrests and a battery operated control system. The user gets to use joystick controls on the armrests to navigate around.

4) Robotics

There have been animals that get hurt and instead of putting them down the owner will find a creative way of helping the animal move around. One way is making a wheelchair for just the front or back legs. The design has two bars that go under the dogs/cats thighs or armpits and are strapped onto the animal over the top of the body. The two bars are also connected to a base that goes between the animals legs to give it stability and that base is connected to two wheels on the outside of the animals thighs or shoulders. This allows the animal to control the movement of the wheels with his body and other legs. Humans have also put lego pieces under a turtle that lost its leg. They attached one lego piece to the body with special surgical glue and superglue (Danger). Then they attached a lego wheel piece onto the piece attached to the turtle. This allowed the turtle to continue to move by using his other legs to give a push.

Danger, Tatiana. "Lego Wheel Turns Tortoise into a Bionic Turtle." *Lego Godt*. KINJA, 7 Nov. 2013. Web. 15 Jan. 2015. http://lego.gizmodo.com/lego-wheel-turns-tortoise-into-a-bionic-turtle-1460195208

5) Walking sticks/canes

If an individual happens to injure their legs or back they can use walking sticks/canes or rolling walkers. Walking sticks/canes are long sticks with a handle at the top so it makes carrying easier. They can be made out of variable materials and can have various designs covering the stick. These are usually used when the back or only one of the legs is injured or lost so it takes some pressure off of the affected area. Rolling walkers have a comfortable seat that is on three or four wheels so you can push from behind. They also have breaks that you can engage to sit down on the seat and a basket to hold things in. Walking sticks/canes and rolling walkers make it a lot easier for people to walk and do basic activities.

6) Blue streak cleaner wrasse, Labroides dimidiatus

Blue-streak cleaner wrasse can be found in the Indian, Pacific, and south Atlantic Ocean (Shea, S. & Liu, M.). These fish can be found near corals and reefs which provide them with shelter and protection. Female blue-streak cleaner wrasse are able to convert themselves into a male if the environment is more suitable for a male. The larger, more dominant female will change genders if the dominant male dies ("SEX CHANGE IN FISH FOUND COMMON"). This will occur so that school of fish can be reproductively sound during any environmental hardships. Researchers are unsure of how the females exactly change into a male but they know it is initiated through social interactions ("SEX CHANGE IN FISH FOUND COMMON"). They believe that hormones and certain genes are triggered to help the female fish change into a male. As they are changing their color, markings, and reproductive organs will alter to make them appear like a male. The last thing that they believe will occur is the start of sperm production in the new testes of the fish ("SEX CHANGE IN FISH FOUND COMMON"). This will allow the school of fish to reproduce efficiently and survive.

Shea, S. & Liu, M. 2010. *Labroides dimidiatus*. The IUCN Red List of Threatened Species. Version 2014.3. Retrieved April 10, 2015, from http://www.iucnredlist.org/details/187396/0.

"SEX CHANGE IN FISH FOUND COMMON." *The New York Times*. The New York Times, 03 Dec. 1984. Web. Retrieved April 10, 2015, from http://www.nytimes.com/1984/12/04/science/sex-change-in-fish-found-common.html.

7) Cuttlefish, Sepiida

Cuttlefish can be found in every ocean and can swim in shallow waters or in the deeper sections ("Cuttlefish"). One of their great abilities is being able to portray one half of their body as a male and the other as a female. This can be very beneficial because if the animal is in an environment where there are too many males and not enough females the cuttlefish can show the female side to the males and the male side to the females, or vice versa. This way the other males won't think it is competition and leave it be. The cuttlefish use their fins and pigment cells to mimic the sex needed ("Anatomy of a Cuttlefish"). The fins are mobile because they don't contain any bone or cartilaginous supporting materials. This means the cuttlefish can move and fold them to make them look like smaller, immature females ("Anatomy of a Cuttlefish"). Cuttlefish also use their 200 chromatophores (piment cells) per square millimeter to make a certain pattern and/or color to make them blend in or attract mates ("Anatomy of a Cuttlefish"). This act

"Cuttlefish." *Cuttlefish (Sepiida)*. A-z Animals, 2013. Web. Retrieved March 4, 2015, from http://a-z-animals.com/animals/cuttlefish/.

"Anatomy of a Cuttlefish." *PBS*. PBS, Mar. 2007. Web. Retrieved March 4, 2015, from http://www.pbs.org/wgbh/nova/camo/anat-nf.html.

8) Clown fish, Amphiprioninae

Clown fish are found in tropical waters near reefs where they can find shelter in anemones ("Clown Fish"). Clown fish have the ability of changing their gender from male to female if their environment changes to better suit females. One instance of this is if the female of a pair were to die. The male would go through physiological changes of his color, size, markings, and sexual organs (Peacock, Richard). The body would also start to produce gametes instead of sperm (Peacock, Richard). The mechanisms on how they exactly change from male to female are still being researched but it is evident that they are intricate, complex, and deliberate. Clown fish changing from male to female is key to the survival of the population because if the majority of the females were to die then it would take a long time to reproduce males to replace all of the females

"Clown Fish." *Clown Fish (Amphiprioninae)*. A-z Animals, 2013. Web. Retrieved March 4, 2015, from http://a-z-animals.com/animals/clown-fish/.

Peacock, Richard. "Sex Change in Nature - Coral Reef Fish." *Sex Change in Nature*. Evolution, 2014. Web. Retrieved March 4, 2015, from http://evolutionfaq.com/articles/sex-change-nature-coral-reef-fish.

9) Parrotfish, Scaridae

Parrotfish can be found in the tropical waters of the Caribbean Sea and Atlantic Ocean (Cox, Ashley). Parrotfish are not only known for their beautiful display of colors but they are also capable of changing their gender due to environment changes. If the only male in the school of fish were to die then the largest female would go through the physiological changes to become a male (Cox, Ashley). They could also change genders to be able to better repopulate the school if they don't have high numbers of fish. Finally they can change genders due to chemical pollutants in the environment. Male fish have been found to start producing oocytes instead of sperm in their testes and can even change genders completely (Cox, Ashley). The mechanisms and hormonal cues that help parrotfish from changing genders is still unclear but researchers are still looking into it. They believe that the changes are linked to social interactions which are the start of the sex change (Cox, Ashley). After it is started researchers believe that certain hormones and genes could be linked to help the fish change color, size, and reproductive organs. Once the animal has changed to the opposite sex the reproductive organs will somehow start to produce the appropriate gametes.

Cox, Ashley. "Sex Change- Taking It To The Fishes." *Sex Change*. Science 2.0, 21 Nov. 2008. Web. Retrieved March 4, 2015, from http://www.science20.com/variety_tap/sex_change_taking_it_fishes_progress.

10) Hawkfish, Cirrhitichthys falco

Hawkfish can be found off of the island Kuchino-Erabu near the southern portion of Jpaan (White, Chelsea). These small fish have the capability of changing from one sex to another and then changing back if the need arises from environmental changes described below. Hawkfish can adapt to environmental changes such as the dominant male dying or a larger dominant male residing in territory. (White, Chelsea). If the dominant male dies then the largest female will go through physiological changes started and dictated by hormones in the body. The mechanisms that are involved have not been discovered yet but the female does change its color, markings, and sexual organs to a males appearance. This helps the school of fish survive because then the new dominant male can start producing sperm that will fertilize the female eggs (White, Chelsea). If the environment was to change to where a larger dominant male came into the territory the previously dominant male would change into a female. They do this because they know they can not beat the stronger male so to better serve the school of fish they revert to female organs and reproduce in that way (White, Chelsea). These mechanisms are also not known on how they can achieve these changes but hormones believe to be the key factor.

White, Chelsea. "Zoologger: Transgender Fish Perform Reverse Sex Flip."*Zoologger: Transgender Fish Perform Reverse Sex Flip*. New Scientist, 6 Jan. 2012. Web. Retrieved March 7, 2015, from http://www.newscientist.com/article/dn21332-zoologger-transgender-fish-perform-reverse-sex-flip.html#.VT1EAK1Viko.

11) Scarlet macaw, Ara macao

Scarlet macaws can be found in Central and South America (Millburn, Naomi). They are known for their vibrant red, yellow, blue and white. Scarlet macaws have the ability of eating unripe fruits and poisonous seeds and still survive.

Scarlet Macaws are known for eating nuts, stems, bugs, snails, seeds, and fruit. The unripe fruits and poisonous seeds can give off chemicals that can kill most animals that eat the product. Unlike other animals, though, the macaw is able to eat these products and live. They do this by also consuming clay that contains small rocks. The clay is thought to actively absorb the poisonous materials and then defecating the clay mixture ultimately gets rid of the poison (Yahya, Harun). The other animals that eat the fruit or seed do not have that product to absorb or get rid of the poison which is why they become poisoned.

Millburn, Naomi. "The Eating Habits of Scarlet Macaw Parrots." *Animals*. Demand Media, 2104. Web. Retrieved February 27, 2015, from http://animals.pawnation.com/eating-habits-scarlet-macaw-parrots-4448.html.

Yahya, Harun. "Wonderful Creatures." *Google Books*. Google, 2014. Web. Retrieved February 29, 2015, from https://books.google.com/books?id=4LuMBAAAQBAJ&pg=PA44&lpg=PA44&dq=how+does+clay+help+macaws+from+getting+poisoned&source=bl&ots=En3Ezm4kZN&sig=yLtpnpEZuwN07eXl-

N334J9U1Gk&hl=en&sa=X&ei=XH82VZrsEIazyATR44GIDA&ved=0CDYQ6AEwBA#v=one page&q=how%20does%20clay%20help%20macaws%20from%20getting%20poisoned&f=false.

12) Spanish shawl, Flabellina iodinea

Spanish shawls are a type of nudibranch which are small creatures that don't have a hard exterior but are just made up of skin, muscle and organs. These creatures can be seen by their vibrant purple, orange, and red color display in shallows, reefs, and near sea vents (Holland, Jennifer S). Spanish shawls have the capability of eating a poisonous organism and living.

Certain nudibranch species eat sponges that are poisonous and potentially fatal to other organisms, but are able to survive without damaging their fitness. In fact, nudibranchs can eat toxic sponges and thrive by adapting and using this toxin in their favor. The nudibranch alters and stores the toxin in their skin, muscles, and organs. (Holland, Jennifer S). If the animal is ever to get in danger it could secret the poison from its skin cells or glands helping to protect itself. Other nudibranch species ingest nematocysts, tightly coiled stingers, after eating another organism that contains nematocysts (Holland, Jennifer S). They will then display the nematocysts on their skin to also protect themselves from predators.

Holland, Jennifer S. "Nudibranchs." *Nudibranchs- National Geographic Magazine*. National Geographic, June 2008. Web. Retrieved March 1, 2015, from http://ngm.nationalgeographic.com/2008/06/nudibranchs/holland-text.

13) Puffer fish, Tetraodontidae

Puffer fish can be found in warmer, tropical waters near reefs ("Puffer Fish"). To intimidate potential predators they have the ability of expanding their entire body to make them look a lot bigger than they actually are. They also have sharp spikes on the surface of their skin that can release toxins. Finally the puffer fish can get bit or eaten and release the toxin as well. The puffer fish does not generate its own toxin but sequesters the toxin by eating a bacteria that produce tetrodotoxin (Carroll, Sean B). As the puffer fish are eating more and more of the bacteria it gets stored in its tissue waiting to be used. The animal that is to get poked or eats the fish will get poisoned. Once in the body system the tetrodotoxin blocks the channels that allow adequate movement of sodium ions across membranes and nerves (Carroll, Sean B). Sodium helps control the movement of electrical currents through the body (Carroll, Sean B). If the currents are stopped then the body cannot respond to its daily activities. This in turn causes paralysis and if left untreated can lead to death.

"Puffer Fish." *Puffer Fish (Tetraodontidae).* A-z Animals, 2013. Web. Retrieved March 8, 2015, from http://a-z-animals.com/animals/puffer-fish/.

Carroll, Sean B. "Whatever Doesn't Kill Some Animals Can Make Them Deadly." *The New York Times*. The New York Times, 21 Dec. 2009. Web. Retrieved March 9, 2015, from http://www.nytimes.com/2009/12/22/science/22creature.html?_r=0.

14) Asian tiger keelback, Rhabdophis tigrinus

Asian tiger keelback can be found in Japan near water sources (Hutchinson, Deborah A., Alan Savitzky, Akira Mori, Gordon Burghardt, Jerrold Meinwald, and Frank C. Shroeder.). These creatures are famous for the ability to eat poisonous creatures and live without suffering any side effects, but they can also received the toxin through in utero. Asian tiger keelback's are known for eating toads that give off a chemical poison named bufadienolides from their skin (Hutchinson, Deborah A. et al). Once the snake has ingested the toad the poison will get stored in glands on the back of the neck until it is threatened or frightened (Hutchinson, Deborah A. et al). The snake can continue to eat more and more toads which builds up the amount and toxicity of the poison in the glands. The other way these snakes can obtain these poisons are through in utero. If the mother was pregnant when she ate the toad it can get passed to the baby which makes it able to defend itself from the very beginning of life outside of mom. The Asian tiger keelback can also biochemically alter and process the poison to make it even more potent than it was in the toad (Hutchinson, Deborah A. et al). This can be very essential in getting away from much larger predators. If a snake were to shoot the poison out of its nuchal glands then it would irritate the airways and affect the heart muscles of the victim (Hutchinson, Deborah A. et al). If the airways remain irritated for too long or become swollen then someone could die from asphyxiation. If the heart muscles are affected then not enough blood could be pumped through the body and it can even stop leading to death. Medical attention would be required to help safe the individual.

Hutchinson, Deborah A., Alan Savitzky, Akira Mori, Gordon Burghardt, Jerrold Meinwald, and Frank C. Shroeder. "Chemical Investigations of Defensive Steroid Sequestration by the Asian Snake Rhabdophis Tigrinus."*Chemoecology* 22.3 (2012): 199-206. *Research Gate*. Web. Retrieved March 28, 2015, from http://www.researchgate.net/publication/225633210_Chemical_investigations_of_defensive_steroid_sequestration_by_the_Asian_snake_Rhabdophis_tigrinus.

15) Great barracuda, Sphyraena barracuda

Great barracuda fish can be found in the tropical and subtropical waters surrounding the equator (Bester, Cathleen). These creatures are carnivores that like to feed on tunas and groupers. The fish that the great barracuda eats is likely to eat algae and potentially benthic dinoflagellates which produce ciguatoxins (Friedman, Melissa A., Lora E. Fleming, Merceds Fernandez, Paul Bienfang, Kathleen Schrank, Robert Dickey, Marie-Yasmine Bottein, Lorraine Backer, Ram Ayyar, Richard Weisman, Sharon Watkins, Ray Granade, and Andrew Reich.). The tunas and groupers are not affected by the toxin but are able to store it in their tissues to use as a preventive measure. Once the great barracuda eats the fish that toxin is transferred into its muscles but the barracuda is not affected by the ciguatoxin as well. If the barracuda was to get caught and eaten by a human then they could get ciguatera fish poisoning (CFP). Once ingested the ciguatoxin acts on the sodium ion channels in cell membranes which induce membrane depolarization in nerve cells and muscles (Winter, F. David, Jr.). This interruption in the sodium ion channel can cause the heart, brain, and other organs to act differently because they are not getting the correct induction. Interruption in nerve signals can create paralysis, hypotension or bradycardia (Winter, F. David, Jr.). The innate and acquired immune system will then start to combat the toxin which can lead to diarrhea, nausea, and vomiting. Ciguatera toxin cannot be destroyed on its own and so medical treatment is advised.

Bester, Cathleen. "Great Barracuda." *FLMNH Ichthyology Department: Great Barracuda*. Florida Museum of Natural History, 2014. Web. Retrieved April 12, 2015, from http://www.flmnh.ufl.edu/fish/gallery/descript/greatbarracuda/greatbarracuda.html.

Friedman, Melissa A., Lora E. Fleming, Merceds Fernandez, Paul Bienfang, Kathleen Schrank, Robert Dickey, Marie-Yasmine Bottein, Lorraine Backer, Ram Ayyar, Richard Weisman, Sharon Watkins, Ray Granade, and Andrew Reich. "Ciguatera Fish Poisoning: Treatment, Prevention and Management."*Mar Drugs* 6.3 (2008): 456-79. *NCBI*. Web. Retrieved April 14, 2015, from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2579736/.

Winter, F. David, Jr. "Ciguatera Poisoning: An Unwelcome Vacation Experience." Baylor University Medical Center Proceedings 22.2 (2009): 142-43. NCBI. Web. Retrieved April 14, 2015, from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2666861/.

Readjust

1) Losing a limb and walking on less legs

After an animal looses a leg the animal has to learn to walk with one less leg. This means that the animal has to learn how to balance, walk, run, and other activities on his remaining legs. Those activities require the muscles, tendons, and ligaments to be strong and comfortable with the position that they will have to be in. The majority of an animals muscles must become stronger including his other legs, abdomen, and chest. If these muscles do not grow the animal will be weak and stumble or be lopsided. The tendons and ligaments must become stronger as well because they will have to do more stabilizing of the other legs since the animal may be lopsided for a while. As the animal becomes stronger physically and emotionally it may start to balance properly like it would have done before it lost its leg. From experience animals are more prone to forget that they had more legs and go back to their normal activities the day after the loss, whereas humans can be more dramatic.

2) Cutting off a tail and learning to balance without it

Animals use their tail not only for signaling their emotions but also for balance. In a study cats were trained to walk across a narrow beam and while they were walking across it the beam would shift laterally suddenly. When the beam moved the cats tail moved in the opposite direction, which allowed the hips to adjust and realign themselves over the beam causing the cat not to fall (Walker et al.). When they severed the sacrocaudal spinal cord the cat was not able to move its tail (Walker et al.). This in turn caused the cat to fall more times when trying to cross the beam and it shifted suddenly. So over time the cat had to strengthen up its core and other muscles to compensate for the lack of control that was lost from the tail being rendered useless. The same idea can be related to an animal that had its tail cut off because it too would have to learn to balance again.

Walker, C., C. J. Vierck, and L. A. Ritz. "Balance in the Cat: Role of the Tail and Effects of Sacrocaudal Transection." *Behavioral Brain Research* 91.1-2 (1998): 41-47. *NCBI*. Web. 8 Jan. 2015.

http://www.ncbi.nlm.nih.gov/pubmed/9578438

3) Going blind and learning to move by sound or touch

If an animal were to go blind they would have to learn to get around by sound and/or touch. Studies have shown that blind people, and theoretically other animals, have heightened sound and touch receptors. Those who have the chance to see things before they went blind have an advantage because they were able to correlate a sound to an object and then can remember the object after going blind. Once the individual goes blind, no matter if it was early or later on in life, the brain is capable of cross- modal neuroplasticity and can change with experience (Bates). This means that the brain has the ability to reorganize itself to where the areas of the brain that were used for sight can now be used for hearing (Bates). The animal will then learn how to move around by the sounds that it is hearing. The animal can also use touch to move around. In a study done by Daniel Goldreich, those who were blind were able to process touch faster because the brain has had to hone in on each specific touch and complete the neural processing in a timely manner in order to survive(Society of Neuroscience).

Bates, Mary. "Super Powers for the Blind and Deaf." *Scientific American Global RSS*. Scientific American, 18 Sept. 2012. Web. 8 Jan. 2015. http://www.scientificamerican.com/article/superpowers-for-the-blind-and-deaf/

Society of Neuroscience. *Blind People Perceive Touch Faster than Those with Sight*. *Society of Neuroscience*. Society of Neuroscience, 26 Oct. 2010. Web. 8 Jan. 2015.

http://www.sfn.org/Press-Room/News-Release-Archives/2010/Blind-People-Perceive-Touch-Faster-than-Those-with-Sight?returnId=%7B0C16364F-DB22-424A-849A-B7CF6FDCFE35%7D

4) Going deaf and learning to use sign language

From the beginning of time when people of different languages came together to trade or talk they had to use visual/physical gestures to get their point across. This can be related to how deaf individuals and animals ‘talk’ to us by using sign language. We point to an object or make a developed gesture and it names the object or makes a sentence. Over time the individual or animal picks up on the sign language and is able to talk to someone else without listening to his or her voice. Humans are capable of better understanding other humans when it comes to sign language because if they are completely stuck on what is trying to be conveyed then they can write it down or lip-speak it. When it comes to humans understanding animals it can become more complicated but after several attempts at guessing the human is sure to figure it out.

5) Losing your teeth

A lot of pets nowadays are getting a lot of their teeth pulled due to tooth decay or infection in the mouth. Animals can also loose their teeth from getting into fights or accidents. When this happens instead of starving to death because they can't chew on hard or tough foods they resort to softer meals. This could mean that they throw a little water on their food to let it soften and then smash it up into smaller pieces with their gums. For pets, their owners could get them canned food, which is usually not hard and comes mixed with a gravy type sauce. This allows the animal to still get all of its daily food requirements without eating disgusting food.

6) Losing your arms

When people lose their arms or are born with deformities they have to learn to live life without them. One man who lives in China lost both of his arms from an electrical shock incident and has learned how to ride a motorcycle (Murano). Instead of his arms the man uses bars that reside under his armpits and attach to the handlebars to steer as he moves his upper body more one way or the other. Another man, Peter Longstaff was born with arm deformities and learned how to use his right foot to open doors, turn on lights, and paint works of art using a mixture of agility and balance (Murano).

Murano, Grace. "10 Most Amazing Armless People." *Oddee RSS*. Oddee RSS, 03 Feb. 2011. Web. 9 Jan. 2015.
http://www.oddee.com/item_97470.aspx

7) One kidney

Humans are normally born with two kidneys but there are some cases in which they are born with only one, which is called renal agenesis (“Living With One Kidney”). If a person is born with just one then the other kidney will undergo a regenerative/compensatory growth phase. The cells in the kidney will proliferate to bring the kidney up to a size that will be more beneficial then stop dividing. We can also have a kidney removed due to disease or a donation (“Living With One Kidney”). There are multiple diseases that attack the kidney leaving it too damaged to repair itself so it has to be removed. Healthy people can also donate one of their kidneys to someone who needs it to survive. So overall even if we only have one kidney we have the opportunity to live normal, healthy lives.

“Living With One Kidney." *Living With One Kidney*. National Kidney Foundation, 2014. Web. 12 Jan. 2015.
https://www.kidney.org/atoz/content/onekidney

8) Bull Sharks, Carcharhinus leucas

Bull sharks can be found in tropical to subtropical coastal waters and in river systems (Curtis, Tobey). The creatures are responsible for more attacks than any other shark because of its available proximity to humans. With all of that being said bull sharks are able to travel from salt waters to fresh waters and back again without a lot of consequences.

Bull sharks have the ability of traveling and living in both salt and freshwater. Researchers have found that these creatures are able to maintain osmoregulation better than other marine animals. Osmoregulation is the ability to regulate the amount of water and electrolytes that are in the circulatory system compared to the outside environment which causes the body to gain or lose water (Ortiz, Rudy M.). The ocean has a lot of salt in it which leads to a hyperosmotic environment and makes the body want to secrete more water to the outside environment. The animals in freshwater are forced to do the opposite. The kidney, rectal gland, and liver have been shown to regulate the water and electrolyte balances in the body more readily in bull sharks than in other sharks. The kidney will remove more urea and less salt than they normally would when in the freshwater which regulates osmoregulation (“How Bull Sharks Can Live in Both Ocean and Fresh Water”).

Curtis, Tobey. "Bull Shark." *FLMNH Ichthyology Department: Bull Shark*. Florida Museum of Natural History, 2014. Web. Retrieved February 18, 2015, from http://www.flmnh.ufl.edu/fish/gallery/descript/bullshark/bullshark.htm.

Ortiz, Rudy M. "Osmoregulation in Marine Animals." *The Journal of Experimental Biology* 204 (2001): 1831-844. *Osmoregulation in Marine Animals*. The Company of Biologists Limited, 21 Feb. 2001. Web. Retrieved February 18, 2015, from http://jeb.biologists.org/content/204/11/1831.full.pdf.

"How Bull Sharks Can Live in Both Ocean and Fresh Water." *Shark Savers*. Wild Aid, 2014. Web. Retrieved February 18, 2015, from http://www.sharksavers.org/en/education/biology/how-bull-sharks-survive-in-fresh-water/.

9) Pink Salmon, Oncorhynchus gorbuscha

Pink salmon can be found in the Pacific Ocean near Canada and the northern states of the United States and then swim inland to fresher water. They can also be found in the northern parts of the Bering Sea (Luna, Susan M., and Armi G. Torres). Salmon have the ability to live in fresh and salt waters.

Salmon are known to swim upstream from the ocean, where they spend the majority of their lives, to the freshwater areas where they lay their eggs. Salmon are known as an euryhaline species which means that it can tolerate a wide range of salt in its environment during different phases of its life which allows it to migrate (Palmisano, Aldo). The salt level is ultimately controlled by osmoregulation in the body. Osmoregulation is the body system's ability to regulate the water to salt ratio in the body compared to the external environment by using the kidney and gills (Ortiz, Rudy M.). The kidney filters out the excess salt into the urine or helps filter the salt in the body further. The gills are also used to conduct more or less water and salt into the body (Palmisano, Aldo). This control helps salmon from losing to much water and dehydrating or getting too much water depending on the environment.

Luna, Susan M., and Armi G. Torres. "Oncorhynchus Gorbuscha."*Oncorhynchus Gorbuscha, Pink Salmon*. Fishbase, 2014. Web. Retrieved February 14, 2014, from http://www.fishbase.org/summary/Oncorhynchus-gorbuscha.html.

Palmisano, Aldo. "Why Do Some Fish Normally Live in Freshwater and Others in Saltwater? How Can Some Fish Adapt to Both?" *Scientific American Global RSS*. Scientific American, 19 Jan. 1998. Web. Retrieved February 14, 2015, from http://www.scientificamerican.com/article/why-do-some-fish-normally/.

Ortiz, Rudy M. "Osmoregulation in Marine Animals." *The Journal of Experimental Biology* 204 (2001): 1831-844. *Osmoregulation in Marine Animals*. The Company of Biologists Limited, 21 Feb. 2001. Web. Retrieved February 14, 2015, from http://jeb.biologists.org/content/204/11/1831.full.pdf.

10) American Shad, Alosa sapidissima

American shad is a saltwater fish that lives in the Atlantic Ocean and rivers that branch off the ocean into the United States (Discover Boating). American shad fish live primarily in the ocean until they need to spawn where upon they swim back into the freshwaters of rivers. The kidneys are the main organ in the body that regulates the amount of salt and water in the body compared to the surrounding environment. When American shad fish are in salt water they must drink the salt water to replace the lost fluids while using specialized gills and their kidneys to get rid of the excess salt (Palmisano, Aldo). When they swim up into the freshwater they must produce more urine to get rid of the excess liquid while holding onto the salt that is available (Palmisano, Aldo). It is thought that the fish must take time to gradually adapt to the changing salinity levels instead of just going from one extreme to the other. If they did not do this then they would have a harder time of surviving in that given environment. This can be seen by how the hatched babies reside in the freshwater environment until a couple of weeks to months have gone by (Palmisano, Aldo). When the baby fish are ready then they will slowly swim to the ocean where they will stay until there are mature enough to spawn.

Discover Boating. "Shad." *Saltwater Fish- Shad*. National Marine Manufacturers Association, 2014. Web. Retrieved March 18, 2015, from http://www.discoverboating.com/resources/article.aspx?id=314.

Palmisano, Aldo. "Why Do Some Fish Normally Live in Freshwater and Others in Saltwater? How Can Some Fish Adapt to Both?" *Scientific American Global RSS*. Scientific American, 19 Jan. 1998. Web. Retrieved March 18, 2015, from http://www.scientificamerican.com/article/why-do-some-fish-normally/.

11) Red drum, Sciaenops ocellatus

Red drum fish can be found in the Atlantic Ocean on the coasts of Massachusetts to Florida and in the Gulf of Mexico ("Red Drum (Sciaenops Ocellatus)"). Red drum fish are anadromous species which means that they travel from salt water to fresh water in order to spawn (Wurts, W. A.). These creatures are able to travel from extremely high salt concentrations to low concentration levels by slow movement through the water and adaptation. In order for the fish to survive such extreme changes they must allow the kidney to adjust and better regulate osmoregulation. Osmoregulation maintains the internal ionic concentrations relative to the external environment (Wurts, W. A.). The kidneys are able to decrease the amount of liquid given off in the salt water environment but facilitate the release of excess salt to help the fish survive. When the red drum swims into fresher water the kidneys start to release more liquid and retain the available salt concentrations (Wurts, W. A.). If red drum fish could not adapt then it would die of dehydration or too much water.

"Red Drum (Sciaenops Ocellatus)." *Red Drum (Sciaenops Ocellatus)*. Texas Parks and Wildlife, 2014. Web. Retrieved March 22, 2015, from http://tpwd.texas.gov/huntwild/wild/species/reddrum/.

Wurts, W. A. "An Evaluation of Specific Ionic and Growth Parameters Affecting the Feasibility of Commercially Producing Red Drum (Sciaenops Ocellatus)." Diss. Texas A&M U, 1987. *OSMOREGULATION, RED DRUM, AND EURYHALINE FISH: ENVIRONMENTAL*

PHYSIOLOGY. University of Kentucky, 1987. Web. Retrieved March 28, 2015, from http://www2.ca.uky.edu/wkrec/reddrumphysiology.htm.

12) Atlantic striped bass, Morone saxatilis

Atlantic striped Bass can be found in the United States and Canada in fresh and salt water ("Atlantic Striped Bass"). When the temperatures start to become warmer this species will swim from the salt water into the fresh water allowing them to spawn. Due to climate change they are adapting and starting to migrate sooner. They are able to go from waters of extreme salinity to waters with very little salt because of their kidneys. Their kidneys control a process called osmoregulation. Osmoregulation is the ability to regulate the internal environment compared to the external environment (Palmisano, Aldo). The gills have adapted to where they can release the extra salt from the body when the fish are in the ocean (Palmisano, Aldo). When the fish are living in fresh water environments the gills will help the body retain the available salt and release the water (Palmisano, Aldo). This will help the kidney not have as much work to do which will help the kidney remain healthy.

"Atlantic Striped Bass." *Species- Atlantic States Marine Fisheries Commission*. Atlantic States Marine Fisheries Commission, 2014. Web. Retrieved April 24, 2015, from http://www.asmfc.org/species/atlantic-striped-bass.

Palmisano, Aldo. "Why Do Some Fish Normally Live in Freshwater and Others in Saltwater? How Can Some Fish Adapt to Both?" *Scientific American Global RSS*. Scientific American, 19 Jan. 1998. Web. Retrieved February 14, 2015, from http://www.scientificamerican.com/article/why-do-some-fish-normally/.

13) Rainbow smelt, Osmerus mordax

Rainbow smelt are native to the United States and can be seen in the Missouri river, Great Lakes, and near Maine in the Atlantic Ocean (U.S. Geological Survey). These fish are able to swim from salt water to fresh water to spawn and they can live in freshwater for an extended period of time as well. Rainbow smelt are able to migrate from one type of water source to the next and survive due to osmoregulation. Osmoregulation is the regulation of ions and water inside the body compared to the external environment (Palmisano, Aldo). Smelt slowly migrate from one extreme to the next so their bodies can adjust to the changing salinity. In the salt water these fish use gills that specialize in removing the excess salt from the body allowing the kidneys to not get over worked and use the water and salt appropriately (Palmisano, Aldo). In fresh water smelt use then use their gills to trap as much salt as they can which helps the kidney obtain the right amount of salt and water and secrete the rest through urine (Palmisano, Aldo). The kidney is the key organ in osmoregulation and so if it gets hurt or dies then the fish will not be able to survive in any environment.

U.S. Geological Survey. [2015]. Nonindigenous Aquatic Species Database. Gainesville, Florida. Retrieved April 23, 2015, from http://nas.er.usgs.gov/queries/factsheet.aspx?SpeciesID=796.

Palmisano, Aldo. "Why Do Some Fish Normally Live in Freshwater and Others in Saltwater? How Can Some Fish Adapt to Both?" *Scientific American Global RSS*. Scientific American, 19 Jan. 1998. Web. Retrieved February 14, 2015, from http://www.scientificamerican.com/article/why-do-some-fish-normally/.

14) Qhino checkerspot, Euphydryas editha quino

The qhino checkerspot butterfly can be found in Mexico and California (Zolfagharifard, Ellie). These creatures are able to survive in the climate and temperatures that have been present since this species was created, but now they are having a harder time. They are struggling to survive because of the climate change. The climate change has increased temperatures to the point that this butterflies could go extinct if they do not learn to adapt (Zolfagharifard, Ellie). They have adapted by moving to higher altitudes which are home to cooler temperatures and more moist environments (Zolfagharifard, Ellie). By learning to adapt the butterflies will be able to survive and pass on the genes and lessons learned on to their progeny so they have the best chance of survival.

Zolfagharifard, Ellie. "Nature CAN Cope with Climate Change: Unusual Behaviour of Plants and Animals Suggests We've Underestimated Their Ability to Adapt, Claim Studies." *Mail Online*. Associated Newspapers, 07 May 2014. Web. Retrieved March 8, 2015, from http://www.dailymail.co.uk/sciencetech/article-2622454/Nature-CAN-cope-climate-change-Unusual-behaviour-plants-animals-suggests-weve-underestimated-ability-adapt-claim-studies.html.

15) Alpine chipmunk, Tamias alpinus

Alpine chipmunks can be found in the Yosemite National Park in the United States of America (Zolfagharifard, Ellie). These creatures forage on nuts and berries that the trees and plants produce in the forest. The global climate change has affected every species on earth including the alpine chipmunk. As the temperatures have increased by 3 degrees Celsius the chipmunks are finding shelter in higher altitudes (Zolfagharifard, Ellie). The higher altitudes allow for the creature to be less disturbed and live in a cooler climate (Zolfagharifard, Ellie). As the alpine chipmunks migrated up in altitude they have adapted and inevitably changed some of their genetic code. When the parents that live in the higher altitudes reproduce they will be able to pass on their new survival genes to allow their progeny to flourish instead of suffer like chipmunks whose parents did not migrate up in altitude before reproducing.

Zolfagharifard, Ellie. "Nature CAN Cope with Climate Change: Unusual Behaviour of Plants and Animals Suggests We've Underestimated Their Ability to Adapt, Claim Studies." *Mail Online*. Associated Newspapers, 07 May 2014. Web. Retrieved March 8, 2015, from http://www.dailymail.co.uk/sciencetech/article-2622454/Nature-CAN-cope-climate-change-Unusual-behaviour-plants-animals-suggests-weve-underestimated-ability-adapt-claim-studies.html.

16) European wasp spider, Argiope bruennichi

The European wasp spider can be found in the Mediterranean regions but has moved northward into Scandinavia, Poland, and the Baltic region (Zolfagharifard, Ellie). These spiders have traveled north due to the climate change affecting the temperatures. The temperatures have been increasing in the Mediterranean section so to escape the heat and allow their species to survive they have adapted. They did this by mating with spiders that can survive in the colder temperatures (Zolfagharifard, Ellie). The European wasp spider will be able to pass on its genes but will also incorporate the genes that allow their progeny to live in colder climates. This inevitably could change the way the spider looks or acts but it will survive.

Zolfagharifard, Ellie. "Nature CAN Cope with Climate Change: Unusual Behaviour of Plants and Animals Suggests We've Underestimated Their Ability to Adapt, Claim Studies." *Mail Online*. Associated Newspapers, 07 May 2014. Web. Retrieved March 8, 2015, from http://www.dailymail.co.uk/sciencetech/article-2622454/Nature-CAN-cope-climate-change-Unusual-behaviour-plants-animals-suggests-weve-underestimated-ability-adapt-claim-studies.html.

17) Nine-banded armadillo, Dasypus novemcinctus

Nine-banded armadillos can be found in North, Central, and South America where it is warm or has mild winters (Harwick, Brian). The climate has started to change increasing the temperatures throughout all of the months of the year. This temperature increase in the northern states is allowing the armadillos to roam further north to get away from the extreme heat. The armadillos also have more room to roam and time to forage for food because the northern states are starting to have warmer summers and milder winters (Harwick, Brian). Researchers believe that they could start moving further up east to Washington, D.C. and potentially New Jersey (Harwick, Brian). This will allow the animals to adapt the climate change and also learn to adapt to their new environments since each state is different from the next. This in turn will allow the fittest animals to survive and pass on the genes while others will die.

Harwick, Brian. "Armadillo Invasion: Warm-Weather Critters Expanding East." National Geographic. National Geographic Society, 8 Oct. 2011. Web. Retrieved March 12, 2015, from http://news.nationalgeographic.com/news/2011/10/111007-armadillos-united-states-invasive-species-animals-environment/.

18) Red-billed gull, Chroicocephalus scopulinus

Red-billed gulls can be found in New Zealand as a native bird (Lou, Nicole). New Zealand's north island has a mild winter and very warm summer, compared to the south island which has heavy winters and mild summers. The temperatures have started to be affected by the climate change which means an increase in temperature during the summer months. This increase in temperature has made the Red-billed gulls adapt by trimming down their fat and overall body weight (Lou, Nicole). Researchers believe that trimming down allows the animal to expel heat faster and more efficiently into the environment because they have a higher skin to physical volume ratio (Lou, Nicole). Trimming down also helps the birds stay cooler because they are not carrying around extra weight. Finally they will have less internal heat since they don't have all of the fat around their internal organs (Lou, Nicole). By adapting to the climate change these birds will be able to survive and not become extinct.

Lou, Nicole. "How To Deal With Climate Change? Adapt." *Audubon*. National Audubon Society, 13 Mar. 2015. Web. March 3, 2015, from http://www.audubon.org/news/how-deal-climate-change-adapt.

19) Wild salamanders in North America

Salamanders are amphibians that rely on damp climates or readily available water sources to keep their skin from drying out (Zolfagharifard, Ellie). Human intervention in our environment has caused a global climate change affecting all animals. This climate change is affecting North American wild salamanders because the temperatures are increasing causing the ground to be warmer and drier. In order for the salamander to survive in the warmer temperatures they must burn more energy and heavily rely on even the smallest of water sources (Zolfagharifard, Ellie). They have also been adapting to the temperatures by passing on genes that code for smaller bodied progeny (Zolfagharifard, Ellie). Those individuals whose have larger bodies will have a harder time surviving and reproducing which in turn decreases the amount of larger bodied genes passed onto the progeny.

Zolfagharifard, Ellie. "Nature CAN Cope with Climate Change: Unusual Behaviour of Plants and Animals Suggests We've Underestimated Their Ability to Adapt, Claim Studies." *Mail Online*. Associated Newspapers, 07 May 2014. Web. Retrieved March 8, 2015, from http://www.dailymail.co.uk/sciencetech/article-2622454/Nature-CAN-cope-climate-change-Unusual-behaviour-plants-animals-suggests-weve-underestimated-ability-adapt-claim-studies.html.

20) Tawny owls, Strix aluco

Tawny owls are white to pale gray owls that are found in southern Finland where colder winters used to bring more snow (Lou, Nicole). Ever since the climate has started to change it has made the winters milder which results in less snow. In order for the tawny owl population to survive they must adapt by changing to a more brown color (Lou, Nicole). Due to natural selection and survival of the fittest, the tawny owls that are darker in color are appearing more in Finland (Lou, Nicole). This means that these owls are passing down the genes for the brown color to future generations so they will be able to survive in the environment that has been altered by the climate change.

Lou, Nicole. "How To Deal With Climate Change? Adapt." *Audubon*. National Audubon Society, 13 Mar. 2015. Web. March 3, 2015, from http://www.audubon.org/news/how-deal-climate-change-adapt.