Paper ID #24692

How Songbirds Learn to Sing Provides Suggestions for Designing Team Projects for Computing Courses

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Abstract

Understanding how our brain works and how we learn is perhaps one of the greatest challenges facing twenty-first computer science. Songbirds are good candidates for trying to unravel some of this mystery. Over the last decade, a large amount of research has been made to better understand how songbirds learn complex songs. The Canary (*Serinus canaria*) and the Zebra Finch (*Taeniopygia guttata*) have been widely used bird models to study these brain and behavior relationships. Like songbirds, we humans are vocal and social learners. In such learners, the development of communication is initially steered by social interactions with adult tutors. In songbirds, song development is further shaped through interactions with peers and by attending to the consequences of others interacting. In this paper, we review three key areas in a bird's brain which perform three specific roles (i.e. actor, experimenter and critic). Similarly, there are three roles (i.e. coder, designer and tester) that are being played in software firms for developing products. We can bring the same roles into the computer science classroom by designing a term project which involves students who play these three different roles. We demonstrate our methodology by showing how it works in a senior level computer science course. We then discuss and qualitatively show the benefits of such a role-based project design.

Keywords

Active learning, Agile Software Development, Experimental learning, Zebra Finches, Term Project Design

1. Introduction

In spite of the increasing demand for computer science professionals in the workforce, computer science education[1] follows the traditional educational paradigm, where knowledge is received by passive learning. By studying songbirds, we understand knowledge is constructed and not received. This process of knowledge construction is very similar to how students learn complex computer science concepts. We, like songbirds, construct our sense of reality out of all the sensory input we receive. We build patterns of the way we think the world works. Humans' and songbirds' brains are similar in that they are both storage and processing units. New sensory input is integrated into already existing mental models and is processed and constructed into our sense of reality.

The format of the paper is as follows. We provide motivation to our methodology by reviewing prior neurological understanding of how birds learn in Section 2. We then provide prior work on three learning areas and their corresponding roles in the birds' brain in Section 3. In Section 4, we draw parallels between the roles in the birds' brain and the three main roles in software development. We then provide our design of a term project using the three roles in Section 5. We then discuss some of the benefits of our methodology and conclude.

2. Motivation

The Zebra finch is a bird species that has been thoroughly studied over the past 40 years for neurological song learning and production circuitry. Key studies[2,3] identified two neurological pathways that participate in song memorization, acquisition and production. At a high level, Zebra finch hatchlings start displaying behavior that resembles singing only few weeks post hatching. Over the next few weeks, the hatchling (young bird) will experiment producing bout of song syllables that resembles a song of an adult colony member tutor (not necessarily their parent). Over time, the sounds that the young bird makes will resemble the tutor song more and more until the new song matures and resembles the tutor's song to a large degree. At some point, the song becomes crystalized and no more learning will occur for the entire duration of the Zebra finch's life. This amazing acquisition of complex behavior (memorization of the tutor song, production of sound by the bird, and adjustment of produced sounds to resemble the memorized song, even when the tutor is not present) shows the complex neurological pathways that play a role into song learning.

An interesting idea we can borrow from Zebra finches is the interactions between different areas of the bird brains to support trial and error learning of a complex task. The interactions of neuron population in different areas of the brain can serve as an inspiration in class organizations with different roles computer science student play and how they interact to solve complex learning problem.

3. Learning areas of the bird brain

In the past few decades, key areas involved in bird song acquisition and production were identified[4,5]. The areas are organized in two separate pathways, the song motor pathway, which in involves 3 brain areas:

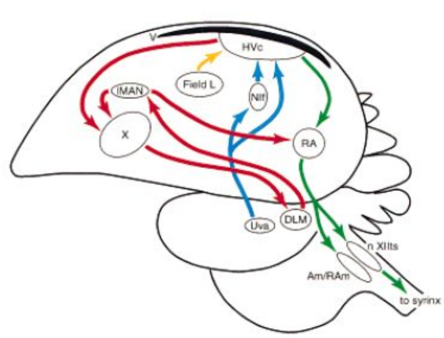

Figure 1: Schematic of songbird brain depicting key areas and pathways (adopted from [6])

a. **Actor**: In the bird, HVC, RA and Motor neurons make up the pathway that produces sounds and plays the role of the "Actor" (shown in fig. 1 in green).
b. **Experimenter**: The second pathway (shown in fig. 1 above in red) plays the experimenter role and involves the AFP pathway – HVC, Area X, LMAN, DLM and VTA. It has been shown that particularly LMAN to RA projecting neurons are active during song development periods in young zebra finches and produce an experimental type of sound behavior, which plays an important part in the learning process.
c. **Critic**: Lastly, researchers were able to identify neurons in adult birds that were active when the bird made an error while trying to produce a previously learned song[4]. The error identifying cells are located outside the traditional bird song pathways and provide input to the AFP pathway in area L (shown in fig. 1 above in yellow).

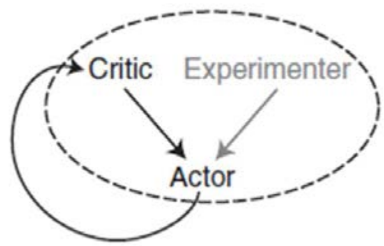

Figure 2: Interaction between Critic, Experimenter and Actor to improve outcome. (Adopted from [5])

Fig. 2 show the interaction between the actor, experimenter and the critic that gives rise to bird song production according to one line of research[5]. Using simulated models, a group of researchers was able to achieve song learning by an artificial neural network with circuitry similar to AFP in relatively short time. Particularly, the interaction between the experimenter and the critic who provide feedback for action taken in the recent past is what allows the network to learn and adapt behavior.

4. Agile Software Development in the Corporate World

Software has been part of modern society for more than 50 years. There are several software development methodologies in use today. Traditional methodologies use comprehensive planning, detailed documentation, and expansive designs for developing software. Since 2001, more recent methodologies such as agile modeling, have gained significant attention from the software engineering community. Some of the characteristics of agile modeling are (a) short development cycles, (b) incremental planning, (c) continuous feedback, (d) reliance on communication, and (e) evolutionary design[7]. Thus, agile software development is an approach to software development under which requirements and solutions evolve through the collaborative effort of self-organizing and cross-functional teams and their end user.

In an organization that uses agile software development, team members spend few minutes on programming, few minutes on design, few minutes on feedback, and few minutes on team building many times each day. We find the same three roles (experimenter: designer, actor: developer and critic: tester) discussed in the previous section, play an active part in the overall development of the product. The better the interaction between the designer, developer and tester roles, the stronger and more productive the team becomes. This way, not only everyone has tasks throughout the agile sprint, but also knows and understands the roles, responsibilities, hard work and effort taken by each member. Thus, the team learns to respect, understand and get on well together to work together with the common goal of a quality product.

4.1 Actor (Programmer)

In bird learning, actors play the part of producing sounds. In software development, actors are programmers who produce code, and gain the operations knowledge needed to support the application in production. These actors or programmers are efficient at breaking down complex scenarios into small programmable chunks, similar to how a bird's brain breaks up a complex song into simpler syllable sequences.

4.2 Experimenter (Designer)

In songbirds, experimenter neurons are active during the initial stages of young hatchlings' song development. In software development, the experimenters are designers who study how the end users interact with the software and systematically design ways to improve that interaction. They also design complex systems. In both cases, the experimenter provides design strategies for the actors.

4.3 Critic (Tester)

Critics are testers who help with the effort ensure the software does what was intended and functions properly. Testers are experts in finding complex scenarios, where they can probably uncover a glitch to break the system. Testers in bird learning provide constant feedback to actors on the overall complex learning process.

5. Methodology: Designing Term Projects in a Classroom

In this section, we describe our innovative approach to designing a term project at a senior level course for students majoring in a Computer Systems degree at a college of technology. The goal of the term project is to develop an end-to-end online airline reservation system using Oracle database. The class of 24 students was divided into 3 groups (Groups A, B, and C). Each student wore three different hats through the three different phases of the project.

Designer (Experimenter) Phase: In the first third of the project, all 3 groups wear the designer hat, where they design the database (using an Entity Relationship Diagram diagram) for building the airline reservation system.

Coding (Actor) Phase: In the next phase of the project, Group A would code or implement the design made by Group B. Group B would code the design from Group C, and Group C will code the design from Group A. All three groups now are involved in the coding phase, and they are not only collaborating with members of their own group but also with the designers from the other groups.

Testing (Critic) Phase: In the third phase, all three groups would wear the critic hat, where they start testing the system. Group A now would test the system built by Group B. Group B would test the system built by Group C, and Group C would test the system built by Group A. Again there is constant collaboration between the coding and testing groups.

As shown in Fig. 3, each student will not only wear the different hats, but will interact with other students about their own work and the work of other students.

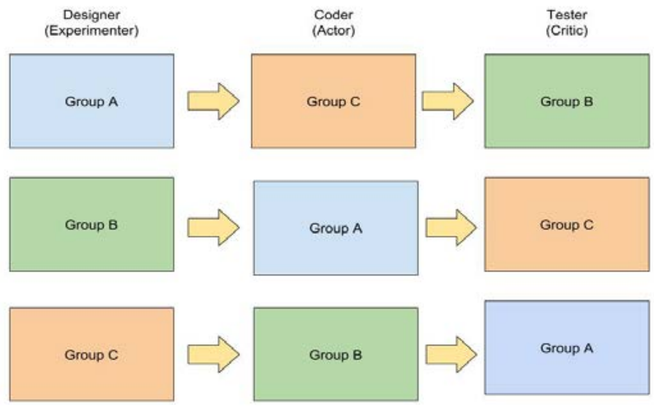

Figure 3: Three different roles of students in a term project for better learning using social interaction and active learning.

We qualitatively measured student satisfaction with our term project model with a survey shown in Fig. 4.

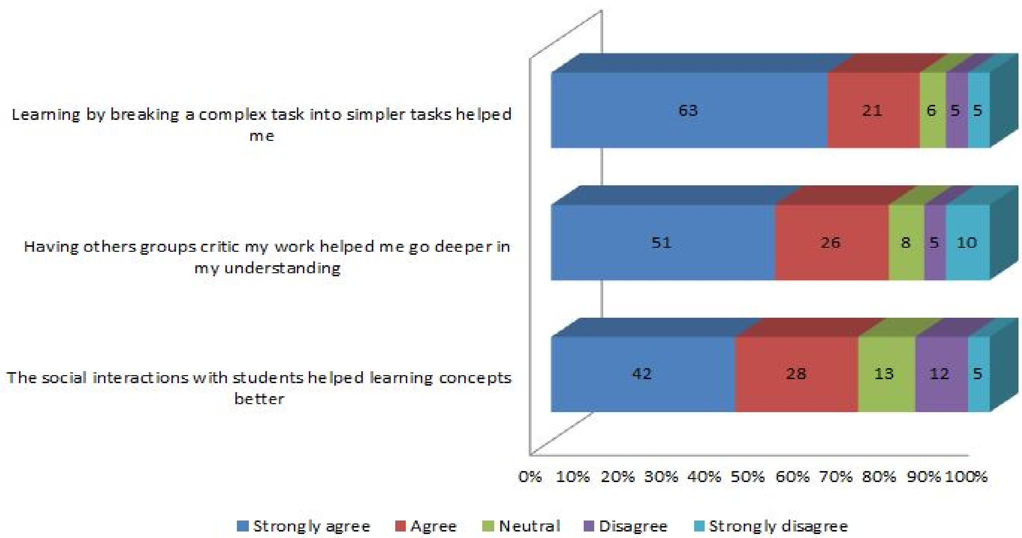

Figure 4: Results of a satisfaction survey (n=24).

6. Discussion: Benefits of having such a model

6.1 Learning by Social Interaction

Researchers[8] scanned the birds' brains and found that the birds who were socialized had higher producing dopamine and norepinephrine centers. These neurotransmitters are known to be involved in learning, potentially because the birds get a reward from the attention involved in this task. The increased amounts in the socialized group may be the reason why they had higher levels of success. The researchers found that the socialized chicks, the ones that were taught by adults, learned the songs much better, even when they only socialized for a short period of time.

Students in the classroom are more productive when there is social interaction between the different roles (i.e. actor, experimenter and critic) of students. It has been shown that having a community of student learners produces better student performance and retention rates[9,13].

6.2 Learning by Breaking Complex Tasks into Simpler Tasks

For a songbird, learning a new song is akin to a computer science student learning a new programming language. Zebra finches approach this challenge step by step, and even make a detour in the process – by taking song syllables that they already know and adapting them to the syllables that they have to learn[10]. During this learning phase, the syllable sequence often gets mixed up. The birds then arrange the newly-learned syllables into the correct order in the next learning phase. For example, let's assume that letters represent different syllables (each of a specific pitch): + and - for a positive and negative semitone change, ++ for a whole tone change. A bird that has mastered song ABC, was given task of learning song AC++B. In a first step, the bird changed the pitch of syllable C and sang ABC++. Only in a second step did the bird arrange the syllables in the correct order AC++B.

Our design of the project where a complex task is broken down into three simpler tasks helps students achieve their end goals using a divide and conquer approach.

6.3 Learning by Trial and Error: Active learning

In the first few months of a songbird's life, they learn the characteristic song of their species. In their experiments, the researchers were able to show that zebra finches can learn by observing fellow members of their species[11]. The birds had to learn through trial and error to discriminate between two classes of birdsong, one long and one short. Without any special preparation, the median number of repetitions it took for the birds to master the task was 4,700. But if the finches were able to observe other finches as they learned this task, then it took them just 900 repetitions. Researchers surmise that although the act of observation involves many synapses between neurons in a finch brain, these are relatively weak. In contrast, trial-and-error learning involves a smaller number of synapses, but they are much stronger, leading to an enhanced ability to generalize.

Computer science students are constantly learning new concepts, but whether they find it easy or hard to generalize what they have learned and apply it to new situations can depend on how they learned it. Active learning, which focuses on experimentation and trial and error, is becoming more and more prevalent in schools and colleges[12]. In our term project, we noticed that students learnt more from other groups through experimentation as shown in Fig. 4.

7. Conclusion

In this paper, we reviewed three areas of the bird's brain which perform three key roles (actor, experimenter and critic) in the process of learning. Similar roles (developer, designer and tester) are employed in software firms today using the agile software development model. We then presented our novel approach to designing a term project in a classroom using the same three roles. We successfully implemented our methodology in one semester of study, and presented student satisfaction numbers. In comparison to traditional term project design, students not only enjoyed this new experience but also learned concepts more quickly.

References

1 Yadav, A., Gretter, S., & Hambrusch, S. (2015). Challenges of a computer science classroom: Initial perspectives from teachers. In Proceedings of the Workshop in Primary and Secondary Computing Education (pp. 136-137). ACM.

2 Nottebohm, F., Stokes, T. M., & Leonard, C. M. (1976). Central control of song in the canary, Serinus canarius. Journal of Comparative Neurology, 165(4), 457-486.

3 Brainard, M. S., & Doupe, A. J. (2002). What songbirds teach us about learning. Nature, 417(6886), 351.

4 Keller, G. B., & Hahnloser, R. H. (2009). Neural processing of auditory feedback during vocal practice in a songbird. Nature, 457(7226), 187.

5 Fiete, I. R., Fee, M. S., & Seung, H. S. (2007). Model of birdsong learning based on gradient estimation by dynamic perturbation of neural conductances. Journal of neurophysiology, 98(4), 2038-2057.

6 Brenowitz, E. A., Margoliash, D., & Nordeen, K. W. (1997). An introduction to birdsong and the avian song system. Journal of neurobiology, 33(5), 495-500.

7 Awad, M. A. (2005). A comparison between agile and traditional software development methodologies. University of Western Australia.

8 Chen, Y., Matheson, L. E., & Sakata, J. T. (2016). Mechanisms underlying the social enhancement of vocal learning in songbirds. Proceedings of the National Academy of Sciences, 113(24), 6641-6646.

9 Cabo, C., & Satyanarayana, A. (2018). Building a Community of First Year Students Improves Student Retention and Performance in Computing Courses. In Proceedings of the 49th ACM Technical Symposium on Computer Science Education (pp. 1084-1084). ACM.

10 Lipkind D, Zai AT, Hanuschkin A, Marcus GF, Tchernichovski O, Hahnloser RHR (2017). Songbirds work around computational complexity by learning song vocabulary independently of sequence. Nature Communications, 1 November 2017.

11 Narula, G., Herbst, J. A., Rychen, J., & Hahnloser, R. H. (2018). Learning auditory discriminations from observation is efficient but less robust than learning from experience. Nature communications, 9(1), 3218.

12 Paradise, R., & Rogoff, B. (2009). Side by side: Learning by observing and pitching in. Ethos, 37(1), 102-138.

13 Cabo, C., & Satyanarayana, A. (2018). Promoting Students' Social Interactions Improves Performance, Class Attendance and Retention in First Year Computing Courses. In 2018 IEEE Frontiers in Education Conference (FIE 2018), IEEE, 2018.

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