BELUGA WHALE INTELLIGENCE AND PROBLEM SOLVING

VIDEO 1 – VISUAL CUE EXPERIMENTS TO STUDY WHALE PROBLEM SOLVING

Will a beluga whale solve problems to get a reward?

Introduction: In 1970, as I was studying for my doctorate degree in bioengineering, I became fascinated with cetaceans, an order of mammals that includes whales and dolphins. My doctoral research had to do with human blood analysis and autoimmune diseases and bore no relevance whatsoever to marine mammals. I was, however, motivated by cetaceans, and it was not long before I started studying them and performing experiments. One of the most scientifically captivating aspects about whales is their large brains, which are typically larger than human brains and can be more convoluted, unlike many other large non-cetacean brains. The large convoluted brains suggest very high intelligence. During this time, I visited the New York Aquarium frequently to observe the whales and dolphins in captivity.

I was given permission at the New York Aquarium to study the behavior of beluga whales, also known as white whales and scientifically as Delphinapterous leucas. Regarding cetaceans, in general, I am not condoning capturing these magnificent animals, except possibly to learn what is best for them. There are pros and cons to captivity. Captivity has perhaps led to greater appreciation for these magnificent mammals and possibly a lower probability of extinction due to human hunting. On the other hand, we have learned that cetaceans in captivity need an environment that we currently cannot as yet provide, a vast environment that enables the extended families, that is: the pods, to flourish. There are also guidelines that should be followed, such as not taking a baby away from its mother. Those who have seen the CNN presentation on television titled Blackfish, a documentary on problems with killer whales in captivity, have perhaps become aware that we must revisit and rethink the captivity issue. I am not arguing for or against captivity, but only to say that if we wish to study the intelligence of a cetacean in captivity, it is essential to provide an environment as close as possible to the natural environment as we can achieve. I should also mention that the natural ocean environment of cetaceans has become compromised in recent years by our pollution. Humans have dumped petroleum, chemicals, plastics, radioactive materials, and other debris into the oceans. There has also been noise pollution from the loud engines of an ever increasing number of oceanic ships.

The results of my experiments, as will be described, were never published, nor were the videos ever shown. These videos were captured on super-8 photographic motion picture film, and this was prior to the wide-scale introduction of videotape and video cameras. After decades of neglect, I decided to describe my research and show the videos. To do this, it was necessary to convert the super-8 film images to digital images, and although the resulting videos are somewhat grainy, most of these super-8 film images came out reasonably well. The resulting videos illustrate the research that was performed in the early 1970's to study and understand whale intelligence, in part by studying how the beluga whale solves problems. Hopefully others will be inspired to pursue similar research.

I might add that the experiments described below in this first section and VIDEO 1 resulted from an initial discussion that I had with the French scientist and expert in bioacoustics, Dr. Rene Guy Busnel. He had studied many bioacoustics phenomena, including dolphin sounds in the wild as well as human whistling languages that evolved independently in separate areas of our planet. Dr. Busnel was a friend of Jacques Costeau and appeared on Cousteau's extremely popular weekly TV show back then. When I discussed my thoughts about experiments to study whale intelligence, Dr. Busnel suggested a line of experimentation using hand signals that resulted in some of the experiments reported here. Another of my mentors in this project was Myron S. Jacobs, PhD, the head of the Cetacean Brain Laboratory and Staff Scientist at the Osborn Laboratories of Marine Sciences at the New York Aquarium. Dr. Jacobs, a neuroanatomist was, even at that time, a world class expert in comparative anatomy of the cetacean nervous system. My chief experimental collaborator was Austin McDevitt, Head Trainer at the New York Aquarium and a former US Navy diver. In addition, there were other trainers and collaborators who participated in the actual experiments. Unfortunately, my notes from many decades ago do not name everyone. Some collaborators, however, may recognize themselves in the videos, and if so I hope that these former collaborators feel free to contact me.

Experiments using hand signals: As can be seen in the accompanying videos, whales and dolphins in aquarium shows visually observe hand signals that are made by their trainer and perform stunts for the audience. These hand signals are developed and used to shape natural behaviors into stunts through many hours of training. Two of the hand signals used frequently were the "kiss", where the whale leaps out of the water and makes contact with the side of the trainer's face and "wave goodbye", where the whale partially submerges and waves a flipper back and forth. When a stunt is performed correctly, the cetacean is rewarded with a fish. The experiments that I will describe consisted of studying what happens with a beluga whale if any of the following occurs: **A)** if the trainer who provides the hand signal wears a disguise; or **B)** if a person unfamiliar to the whale provides the hand signal; or **C)** if a 3-dimensional representation of a human gives the hand signal; or **D)** if a 2-dimensional representation of a human gives the hand signal. These situations may be viewed as problems presented to the whale, where a correct solution results in a fish as the reward.

Although only two beluga whales were studied in this set of experiments, most experiments were performed by a whale named Alex, who at the time weighed 730 kilograms, measured 4 meters in length, and was approximately 13 years old. At the time, Alex had been participating in the New York Aquarium whale-dolphin show for 18 months. The other whale, named Ethel, weighed 460 kilograms, measured 3.6 meters in length, and was approximately 9 years old. After Ethel had undergone 7 months of training as a show animal, some of the experiments performed with Alex were repeated with her. All experiments were performed at the New York Aquarium and in conjunction with Austin, the head trainer at that time. In many experiments, both Alex and Ethel were present. In some experiments, there were also present in the pool several Pacific white-sided dolphins, known scientifically as Lagenorhynchus obliquidens, and more commonly as "Lags".

Our visual cue experiments were performed with the same cues as were used in the training sessions and shows conducted at the aquarium. The method of presentation or "configuration" of the cue was our experimental variable. For example, the same cue could be given by a disguised person or by a dummy. The official training sessions and shows were conducted by a trainer at the aquarium for the public on a regular schedule of 5 times per day 6 days per week, each session equaling 15 to 30 minutes.

In contrast, our experiments were conducted infrequently, typically every other week, to provide a sampling of behavior. On each occasion that an experiment was conducted, two or more visual cues from a repertoire of perhaps six or more were presented and the entire sequence repeated typically once. The experiments began in 1972 and were conducted for more than a year. In our long term memory experiment, we halted all experiments for 14 months before starting again.

Results: In all cases, the results were unambiguous. When a visual cue was given, the whale either responded within the first minute or did not respond, even after 5 minutes. Alex responded correctly to cues presented by a disguised trainer, such as a trainer wearing a raincoat and gasmask, and to visual cues presented by unfamiliar humans. There were no correct responses when a life-size 3-dimensional dummy was for the first time held in front of and manipulated by the trainer. Nor did Alex respond to the hand signals when the trainer was covered by a bed-sheet, unless the trainer's face was exposed. However, when the trainer was covered by a bed-sheet that had eyes, a nose, and a mouth sketched over the blank face and the visual cues were presented, correct responses resulted. Interestingly, from that time on, Alex would respond to a faceless dummy as well, apparently making the mental leap that a face was not required. At this point in time, a dummy could run the show!

Soon afterward, Ethel, the female beluga whale, was introduced into the experiments. She quickly learned to respond to cues given by the 3-dimensional dummy. She did not, however, respond to a doll-sized dummy, nor did Alex. When a 2-dimensional life-size dummy (made from a large piece of painted cardboard) was introduced, Alex hesitated at first, but then quickly began to respond to the visual cues given by this manipulated 2-D dummy. Ethel never responded to this 2-dimensional dummy. During that time, she became uncooperative in the training sessions and shows as well as in our experiments. Subsequently, she was moved to another pool.

After a 14 month postponement of all experiments, the 2-D dummy was again presented to Alex. He did not respond to any of the visual cues given by this manipulated dummy but instead swam in slow, deliberate circles around the pool. This behavior was well known to us and classified as "investigatory" as opposed to "refusal to respond". Painting a face on the 2-D dummy elicited the same type of investigatory behavior. Presentation of the faceless 3-dimensional dummy, however, resulted immediately in correct responses. This result was very striking when compared with several repeats of the 2-dimensional dummy experiment in which there were still no responses. Finally, after many more trials that day, Alex began to respond to the 2-dimensional dummy. His responses were reminiscent of early learning behavior.

Conclusions and Discussion: We concluded that the whales were able to respond to a visual cue, given in the form of hand signals, without distinction as to who gives the cue. For a particular visual cue, the whales could generalize further to a "representation" of a human, such as a life-size 3-dimensional dummy. Also, we observed that once the whale responded correctly to a cue given by a particular configuration (i.e. dummy, disguised trainer, etc.) the animal will respond to any previously learned visual cue given by that configuration. At first, the male beluga whale did not respond to a faceless dummy or a trainer with a bed-sheet over his head but was later able to do so. We may therefore conclude that facial lines or features were somehow important. Size was important, since there was no response to a doll-sized dummy held in front of the trainer. Perhaps this was due to the visual dominance of the operator standing behind the small dummy. Whether correct responses would have been obtained with the trainer behind a screen and only the doll-sized dummy showing was not tested in this set of experiments. The male beluga whale made the transition from a 3-dimensional dummy to a 2-dimensional dummy after initial hesitation. That there was indeed a perceptual difference between the 3-D and 2-D dummy configurations was borne out when both dummies were again presented 14 months later. In this instance, the 2-dimensional dummy was apparently forgotten, and there was also a failure to generalize after presentation of the 3-dimensional dummy. Failure to recognize the 2-D dummy may have resulted, at least in part, from fewer presentations and reinforcements for the 2-D dummy than for the 3-dimensional dummy. Prior to the 14 month cessation of all experiments, the 2-D dummy had been presented on 4 occasions over a 1 month period as opposed to 18 occasions over a 12-month period for the 3-D dummy. It seems, therefore, that the relationship between 3-dimensional and 2-dimensional patterns may not be as obvious to a beluga whale as would be expected for most humans participating in a similar experiment.

A most striking result was the response to the 3-D faceless dummy after the 14-month hiatus. The whale did not initially respond to this dummy but learned to do so during our experiments. This post-hiatus result may be indicative of a good long term memory. The conditioning influence of the scheduled daily training sessions and shows at the aquarium may be considered as a baseline and the actual experiments that we performed as a deviation from the baseline.

Part 1. Selected Videos (1-10, below)

[1] Typical correct responses to trainer –

One of many videos made of beluga whales responding to hand signals given by the trainers at the aquarium.

[2] Trainer w. gasmask, hat, etc. –

For the first time, a trainer wore a disguise and delivered hand signals to see how the beluga whales would respond. They responded normally.

[3] Trainer w. gasmask, gloves, raincoat and hood –

In this case, a more complex disguise was worn by the trainer to see if the typical beluga response to hand signals would be obtained. Typical beluga responses were obtained.

[4] Unfamiliar person replaces trainer –

What if the trainer is replaced by a complete stranger (in this case me). Would the beluga whale still respond to the hand signals? Yes, he certainly did.

[5] Three dimensional dummy gets no responses –

When a 3-dimensional representation of a human, i.e. a dummy, was held in front of the human and the dummy's arms manipulated to produce hand signals, the beluga whales did not respond. Finally, we had reached a new level.

[6] Trainer w. bedsheet over body/face –

When a trainer disguises himself as a dummy by placing a bedsheet over his head and upper body to see what the beluga whale response to the hand signals will be, no response resulted.

[7] Trainer w. bedsheet, face showing –

When the same trainer, who disguised himself as a dummy by placing a bedsheet over his head and upper body, then exposed his face, the whales responded normally to the hand signals. This suggested that faces or facial lines were somehow important to the belugas.

[8] Trainer w. bedsheet w. painted face –

When a trainer was disguised as a dummy, using a bedsheet over his head and upper body, but also had a simple face (eyes nose and mouth) drawn on the bedsheet with a marker pen on the area corresponding to his face, the whales responded normally to the hand signals. This also suggested that faces or facial lines were somehow important to the belugas.

[9] 2-D Dummy without face painted on it –

Whereas we had figured out that facial lines were somehow important to the belugas, the belugas were apparently also figuring things out. At that point in time, presenting a 3-dimensional dummy with no face resulted in correct responses. Both whales responded to the 3-dimensional dummy with or without a face drawn on it. When a 2-dimensional dummy with no face was introduced, only one of the whales, Alex, responded quite easily.

[10] 3-D Dummy w. face painted on it –

As mentioned above, both whales responded to the 3-dimensional dummy with or without a face drawn on it.

[11] Trainer w. Alex & Ethel, including fetch –

This video shows two belugas, Ethel and Alex, responding to a variety of hand signals and fetching a ring.

[12} Trainer w. Alex & Ethel & 2-D dummy –

This last video of Part 1 shows how Alex, but not Ethel, responded to the 2-dimensional dummy.

Cetaceans at Night: Whales Do Not Sleep.

In a short time, I got to know a number of people at the New York Aquarium. As I mentioned, one very inspiring person was Myron S. Jacobs, PhD, the Head of the Cetacean Brain Laboratory and Staff Scientist at the Osborn Laboratories of Marine Sciences, New York Aquarium. Dr. Jacobs, a neuroanatomist, was studying and mapping the brain of the beluga whale. He pointed out to me that the beluga whale has a brain slightly larger than that of a human. He also indicated that the ratio of the number of nerve fibers coming from the ears to the brain vs. the number coming from the eyes to the brain is much higher in the beluga than in the human. That is, although the total number of nerve fibers from the eyes to the brain plus from the ears to the brain is not that much different in the beluga whale and human, the ratio of auditory information vs. visual information sent to the brain is much higher in the beluga than in the human. This suggests that human perception is more visual than for the beluga, and beluga perception more auditory than for the human. He then showed me his brain map and pointed out the motor cortex, used to operate the muscles in the body, and the sensory cortex, used to process all sensory information. He also indicated a part of the brain known as the association cortex, involved in integrating the information from the motor cortex and sensory cortex, and also believed to be related to intelligence. He then pointed out that the association cortex is proportionally larger in the beluga than in the human. Given this new information, how could I not pursue studying the problem of whale intelligence?

One of the things that fascinated me was that several trainers at the aquarium were of the opinion that cetaceans do not sleep. I could not believe this. From my studies in medical physiology, it was clear to me that sleep has several stages including rapid eye movement or REM sleep. One stage, however, is that of the deepest sleep, sometimes called: slow wave sleep, deep sleep, or delta sleep. In slow wave sleep, there is no eye movement or muscle activity. It is very difficult to wake a person up from this stage, and this stage is absolutely necessary for the brain and for survival. I simply did not believe that cetaceans do not sleep.

Surprisingly I got permission to spend the night at the New York Aquarium to observe the lack of sleep in the beluga whales. Apparently, there were staff members at the aquarium throughout the night, and it was not a big deal for me to sit in a dark underground location next to the glass window of a beluga whale holding pool where the whales stayed at night and for me to observe the whales throughout the entire night. There were four belugas in this well illuminated holding pool. All four were together and situated near the bottom of the pool. I could see them, but they couldn't see me. I had plenty of coffee and NoDoz caffeine tablets to stay awake all night.

As the night got later and darker, I observed that all four whales surfaced for air a bit less frequently, and their other swimming tended to be less pronounced and eventually ceased. Other than coming up for air, they seemed to be relaxing. Their eyes rarely closed, and when their eyes were closed, it was only for seconds at a time. At dawn, I was convinced that all four beluga whales had slowed down their activity levels but did not sleep, or at least undergo sleep as we know it.

After I returned home, I went to sleep. The next day I thought about this a lot. It occurred to me that since cetaceans have to come up for air to breathe they cannot afford to sleep as humans do and risk drowning. Yet the brain absolutely requires sleep. Therefore they must put parts of the brain to sleep while other parts are awake. I then thought of the cat and the dog, both very familiar animals to me. It is difficult to say which is more intelligent a cat or a dog. A cat has a smaller brain than a dog, yet the cat spends a greater proportion of its life sleeping than does a dog. So perhaps a larger brain enables some animals to exist on less sleep. This might explain the large cetacean brain size and suggest that the cetaceans are not more intelligent than humans, even if they have larger brains. To achieve the physiological phenomenon of less sleep or no sleep at all, as we know it, a larger brain is probably needed.

Back then, in the early 1970's, it was perhaps a radical idea to suggest that parts of the brain sleep while other parts are wide awake, but today, based on relatively recent research with electro encephalogram (EEG) recordings of cetacean brain activity using electrodes on the head, as well as brain scans, it appears that cetaceans and some birds have the ability to put one hemisphere of the brain to sleep at a time for survival purposes and to not ever sleep fully with both cerebral hemispheres the way humans and many other animals do.

Links to Research on Sleep in Whales and Dolphins

Unihemispheric slow wave sleep

http://en.wikipedia.org/wiki/Unihemispheric_slow-wave_sleep

Do whales and dolphins sleep?

http://animals.howstuffworks.com/mammals/question643.htm

How do dolphins sleep?

http://www.livescience.com/44822-how-do-dolphins-sleep.html

'Brain-juggling' lets dolphins avoid sleep deprivation

http://www.newscientist.com/article/dn17059-brainjuggling-lets-dolphins-avoid-sleep-deprivation.html#.VPPq4mc5Apc

Sleep (non-human)

http://en.wikipedia.org/wiki/Sleep_(non-human)

Disadvantages of unihemispheric sleep

http://biology.stackexchange.com/questions/3241/disadvantages-of-unihemispheric-sleep

Journal Articles & Videos

http://www.sciencedirect.com/science/article/pii/S0149763400000397

http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2869.1994.tb00123.x/abstract

https://www.youtube.com/watch?v=nc4fKr-5J-I

http://www.ncbi.nlm.nih.gov/pubmed/11118608

VIDEO 2 – Cetacean Problem: Examining Unfamiliar Objects

How does a beluga whale examine an unfamiliar object?

Introduction: In the early 1970s, when I began studying beluga whales at the New York Aquarium, one of my experiments was to study how beluga whales examine unfamiliar objects. This was a prelude to the "Two Whale Communication Experiment" that I never performed but is described separately as the "AHA" Experiment at the end of this paper. One of the first experiments was to suspend a 2.5 pound barbell weight, consisting of a composite material with a hard plastic shell on a thin piece of rope in one of the whale and dolphin pools. Attached to the rope and weight was a small hydrophone to record audible clicking echolocation pulses. It should be noted that some very high frequency ultrasonic clicks could not be heard and recorded with the equipment used, but the objective here was to determine only if the whale was using echolocation on this unfamiliar object attached to the rope.

The result from studying several beluga whales was that there were apparently several stages of examination of this unfamiliar object.

1. When the unfamiliar object was immersed in the water, the beluga whale, as seen in one of the videos, first stayed at the other end of the pool, keeping a good distance from the object and then swimming back and forth while emitting echolocation clicks, as detected via the hydrophone.

2. The whale then swam in circles, closer to the object, occasionally emitting clicks.

3. He then began swimming in wide circles, passing the object and expelling water with his mouth to push the object and observe what happened and how it moved.

4. Then he grabbed the object in his mouth, apparently gingerly and with finesse, emitting clicks, audible via hydrophone, while holding onto the object.

5. Finally, he began to play with the object, as seen in the video.

The biggest surprises to us were: a) the whale's use of expelled water, apparently to study the object's mass and motion; and b) the continued clicks for an extended period of time while the object was in the whale's mouth. The latter observational behavior was suggestive of combined proprioception and proximal echolocation sensory modalities in his examination of the object partially contained in the mouth.

Unfamiliar Object Examination: Selected Videos (1-7, below)

[1]Alex echolocates/examines barbell weight (with hydrophone)

[2]Alex and bouncing weight (w/o hydrophone)

[3]Blanchan examines weight with sponge

[4]Alex examines seashell

[5]Alex examines small piece of forged metal

[6]Alex examines weight with sponge

[7]Alex examines two weights, the upper weight with a hydrophone in the center

VIDEO 3 – Whale Observations near the Saguney River

How do beluga whales behave in their own natural environment?

Introduction: In September 1973, near the end of my whale research, I led an expedition, primarily with my friends from the New York Aquarium, to the Saguney River in Quebec Provence in Canada. The purpose of this trip, lasting several days, was to observe beluga whales in their natural environment and to identify behavioral differences relative to the beluga whales in captivity that we had studied. The Saguney River empties into the St. Lawrence Estuary, at the town of Tadoussac (Tadoussac is not shown on map below).

Saguney River and Tadoussac: Near the lower left corner, the St. Lawrence River (not labeled) passes Quebec and becomes the St. Lawrence Estuary (not specifically labeled either). The Saguney is the narrow river flowing from the NW into the estuary about midway between Quebec City and Mont-Joli, both at the left third of the map. The Saguney enters the estuary at the town of Tadoussac (not identified on this map).

Estuary and Gulf of St. Lawrence: [From: http://www.qc.dfo-mpo.gc.ca/golfe-gulf/index-eng.html] The St. Lawrence River begins as the outflow of the Great Lakes and widens into a large estuary near Ile d'Orléans, adjacent to Quebec City (lower left corner of map) where the river's fresh water first encounters oceanic salt water and the typical two-layer estuarine circulation begins. Continuing downstream, the surface water of the St. Lawrence becomes more increasingly salty, finally having a true oceanic character at the head of the Laurentian Channel (off-shore of Tadoussac), where strong upwellings bring deep waters to the surface. Among the deepest and largest estuaries in the world, the St. Lawrence estuary extends nearly 250 km before it widens into the Gulf of St. Lawrence. This enclosed sea is connected to the Atlantic Ocean by Cabot Strait and the Strait of Belle-Isle at the lower right of the map prior to the Atlantic Ocean and at the upper left of the map, respectively.

Whales in the Saguney River: The Saguney River is a fresh water river flowing into the estuary. Whales, including beluga whales, frequently swim up the Saguney to feed on fish. At a park near the town of Tadoussac, we camped out at night and spent most of one day on a rented boat and most of another day on a second, larger boat. We had many opportunities to see beluga whales in groups, called pods. These groups were surprisingly spread out, yet the individual whales coordinated with each other, often surfacing at the same time from different locations to exchange air. On the second boat that we traveled on, a large pod of whales, consisting of about 50 belugas, surrounded the boat and all spouted at the same time – almost as a salute to the boat or its captain. It was an impressive sight, and it made one think that the whales confined in small tanks that we had been studying were like prisoners, confined in small cells. The behavior of the beluga whales in the wild appeared to be quite different from that of the whales in captivity. In the wild it was a social event, involving group behavior. Recalling the behaviors of the belugas in captivity, it seemed as though we were dealing with solitary whales, deprived of the social units that enable them to flourish.

In addition to the belugas, we also came across three baleen whales that were continually diving, presumably to feed on fish. Baleen whales, one of the two suborders of cetaceans, have whale bone instead of teeth and strain the water to retain large amounts of krill, other crustaceans, and small fish. The toothed whales are the other cetacean suborder and include dolphins, belugas, killer whales, and others, with the sperm whale being the largest toothed whale. The largest baleen whale is the blue whale, believed to be the most massive animal ever to have lived on earth, outweighing the largest of the dinosaurs. Larger baleen whales tend to have large brains and long lifespans. Bowhead whales that were recently killed still had harpoons in their bodies from about 1890 which, along with analysis of amino acids, indicated a maximum life span of from 177 to 245 years old. At the Saguney River, we were unable to positively identify the species of the three baleen whales that we observed continually diving near the shore.

Each of the baleen whales that we observed at the Saguney was about 30 feet long, and all three were diving to considerable depths, based on the speed of the dive and the time until surfacing. Our group was sitting near some rocks, eating lunch, and watching the baleen whales dive for nearly an hour. Near the edge of this part of the shore, the water was believed to be several hundred feet deep. We knew that the water was quite deep right near us, and to our surprise the whales gradually drew closer to us over time as we enjoyed our lunch, presumably because they were curious, and never ceasing their continual diving. After a while, they made a few dives that were close enough – perhaps only 15 feet away – to make direct eye contact while continuing their diving and feeding. It was quite a sight.

Whale Observations near the Saguney River: Selected Videos (1-3, below)

[1]Scenes from the Saguney River w. belugas

[2]Observing baleen whales near the river

[3]More belugas

GRAND CONCLUSION: The "AHA" Experiment

The "AHA" Experiment that this was All Leading to: In the two videos of experiments performed at the New York Aquarium, some of the results of the visual cue experiments performed by the trainers and the beluga whales can be seen as well as how belugas examine unfamiliar objects: that is, objects that they have never seen before. All of this was leading up to what I call "The Two Whale Communication Experiment", which I never performed, but which I believe is entirely possible, and will, perhaps someday be performed.

Using echolocation, cetaceans emit sound pulses, and their brains most likely process the echoes that come back to them, along with the original sound transmission to produce images of what the sound bounced off of. This capability is well known and a bit like sonar, only more sophisticated. When I was performing experiments with the beluga whales, I hypothesized that whales and dolphins may have evolved unique communication systems, based on sound waves but quite different from human languages. I believe that whales and dolphins are able to send each other echolocation signals (primary sound pulses) as well as simulations of the echo (secondary sound pulses) that they received from a prior echolocation. The cetacean brain should be able to convert the primary and secondary sound pulses into an echolocation image. Thus, by sending both primary and secondary pulses, with the appropriate time delay, one whale should be able to communicate to another via a picture or perhaps a cartoon or a simple sketch of what they observed from a prior echolocation experience. This type of communication would be a pictorial language that they can use, quite unlike the language that humans use, which – in the case of humans – has been theorized as an evolution from facial expressions into sounds, enabling early humans to make facial expressions in the dark.

This hypothesis of whale and dolphin communication has never been proven, and I doubt that it has ever been properly tested. Hopefully, someday an appropriate experiment will be performed to test this hypothesis. I will outline my experimental approach below for "The Two Whale Communication Experiment", which I set out to pursue but was dissuaded by several of my mentors in the medical diagnostics field, where I was actively experimenting and publishing at that time, and who thought it would be a very, very long term project unlikely to be funded by any existing scientific research granting agency any time soon and therefore not a good choice for my future career. As motivated as I was at that time, I listened to my mentors and ceased working on the whale project. Perhaps others will be inspired by my initial results to pursue a similar approach in the future. This is, in part, why I have decided to describe the ideas and results after so long a time. The tipping point that set me in motion was the CNN television presentation: Blackfish.

The Two Whale Communication Experiment: After spending a lot of time thinking about how one would demonstrate that whales might be able to communicate via sound waves using pictures, cartoons, or sketches, I devised what I call the Two Whale Communication Experiment.

The object is to have two whales, each in a partitioned section of the same pool. The pool would be divided evenly in the center by a solid wall that is essentially a sound-insulating barrier with an underwater opening in the barrier covered by a removable hatch, enabling passage of echolocation sounds when the hatch is removed. Unfamiliar objects could be presented underwater to each of the whales individually on their side of the barrier and would be achieved with the hatch in place and the underwater opening closed off.

Alternatively, the whales could be situated in two adjacent pools, connected by a water-filled conduit, enabling passage of echolocation sounds through the water. This conduit would be too small for the whales to move through, and unfamiliar objects immersed in the water and presented to each of the whales individually in their respective pools would take place in an area of the pool not in the line of sight. Sound communication through the conduit could be turned off by placing a sound-insulating cover in either pool to close off the water-filled conduit.

The experiment would proceed as follows.

1) The first whale (Whale No. 1) would be presented with an unfamiliar object, immersed or suspended in the water for examination. [The results might be similar to what was obtained in VIDEO 2 for the beluga whales examining unfamiliar objects.]

2) Afterward, the two whales would be allowed to communicate, **a)** via lifting the removable hatch covering the underwater opening in the case of a single pool with a barrier or **b)** via lifting the sound-insulating cover in the case of two connected pools to reestablish sound transmission between the two pools so whales could swim toward and communicate via the underwater conduit.

3) Then the second whale (Whale No. 2) would be presented with several unfamiliar objects, e. g. a total of five, each suspended in the water for examination. This would be completely out of the line of sight of Whale No. 1. If Whale No. 2 selects the same object that the first whale (Whale No. 1) was presented with immediately prior to this (that is: the correct one of the five) then a uniquely characteristic whistle or horn would blow and both whales would be rewarded with fish.

4) The experiment could also be periodically reversed, with Whale No. 2 examining the unfamiliar object and Whale No. 1 making the selection from the set of unfamiliar objects.

5) It should be possible at this point in time to continue these experiments with the same unfamiliar objects and also with new sets of unfamiliar objects to see if the rate of successful selection of the correct object (I in 5 or 20% for a random guess) approaches 100%. The only way that a whale can achieve a high probability of success in selecting the correct unfamiliar object from a set of unfamiliar objects would be if the first whale can communicate the correct object, e.g. via an image, to the second whale when the two whales are allowed to communicate. This communication would always be encouraged, via sound barrier removal, prior to the second whale being presented with the set of objects for selection of the one that will result in a reward for both whales.

Ruling out mental telepathy as a possible form of communication, successful selection of the correct unfamiliar object could be achieved via a language, such as human languages, or via sign language using appendages, or via a pictorial communication using an acoustic image that describes the correct object. It is reasonably well established that cetaceans do not have a human-type language for communication and do not have human-like appendages capable of intricate sign language. So if the experiment proves to be successful, and a higher proportion of correct answers than would be expected by random chance is the result, the next step would be to determine the exact nature of the communication and how it is achieved, presumably via acoustic means. This could involve the use of an array of acoustic sensors, processing the sound digitally, analyzing temporal characteristics, and through the use of sonar-like computational and visualization methodology for display.

Hopefully, someday, someone will try this set of experiments or a similar one to determine exactly how cetaceans communicate. And if the AHA experiment is successful, and the whale communication hypothesis proven to be correct, demonstrating that whales, and perhaps all cetaceans, communicate in a pictorial language, could we then make use of our sound processing technology to communicate with them, perhaps as we have in the past communicated with selected chimpanzees using sign language? If so this would be very different, since we taught the chimps our sign language, but the whales have developed their own language, one that is highly evolved, visual, and spatial – based on sound – and perhaps pictographic and/or symbolic. If such communication capability could be developed and used to communicate with whales underwater, perhaps at great distances, what might come from this cannot be fathomed at this point in time, but perhaps the outcome of such interspecies communication between humans and the ambassadors of the oceans would ultimately be astonishing.

ADDENDUM

After I had written the material above in this white paper, I discovered that a report had been posted on www.speakdolphin.com by Jack Kassewitz and his collaborators in 2011 about some experiments where dolphins used echolocation to explore unfamiliar objects, such as a plastic cube, a toy duck, and a flowerpot. When the sounds of the echoes or reflected sounds from an object were recorded and played at a later time to the dolphin, in the format of a game, the dolphin was able to identify the objects from the recorded echoes with 86% accuracy. Kassewitz than drove to a different dolphin facility a distance away and replayed the sound to a second dolphin who had not experienced the objects previously, and apparently the second dolphin identified the correct objects from their recorded echoes with a similar high success rate. I have since contacted Jack and learned that this work has continued, and additional studies, including those with a CymaScope for visualization of sound vibrations from dolphin echolocation captured with hydrophones and 3D printing of some of the images have been performed. These are reported in an eBook, recently published and available on Amazon, by Jack Kassewitz, James Denny Townsend, and Jim McDonough, titled: Speak Dolphin – Deciphering the Dolphin Code.
See: http://www.amazon.com/SPEAK-DOLPHIN-DECIPHERING-THE-CODE-ebook/dp/B00XQIDNR0 .
Although comprehensive studies of the type that would appear in a peer-reviewed scientific journal have not as yet been completed, there is now ongoing work that supports the idea that dolphins may use a pictorial language.