Coriolis merry-go-round

Aim: To have students experience forces (centrifugal and Coriolis) in a rotating frame of reference.

Subjects: 1E20 (Rotating Reference Frames)
1E30 (Coriolis Effect)

Diagram:

Equipment:

- Merry-go-round; diameter = 6 meter; closed to the outside world.
- Basketball.
- Plumb line.
- High speed gyroscope.
- Rifle (fixed firmly on a support) and target.
- Water-basin, (with a central drain) that can easily be levelled horizontal (for standing still and in case of rotation).
- Instructor and students (maximum 12).

TU Delft

Coriolis merry-go-round

Safety:

- The merry-go-round rolls with rubber wheels over a circular rail. A round-going sheet of stiff rubber prevents that the wheels can be touched (see the black rubber sheet in the pictures in Diagram).
- On both sides of the merry-go-round there is an emergency-stop button. Just hitting one of these buttons will stop the merry-go-round immediately. Also on the inside there is such an emergency-stop button.
- When a group is practicing inside there has to be an observer outside the merry-go-round to take care of the safety.

Presentation: We have merry-go-round sessions with 12 students at a time. In such a session, experiencing Coriolis-force by the students is the main objective. To limit the experience to the rotating reference frame, there are no windows and both doors are closed. (No sight to the outside world also limits the chance of becoming sick.)
The students enter and position themselves along the wall (not leaning against, but free from the wall).

Standing still.

When the group is inside we first observe some phenomena while the merry-go-round is still standing still:
-Watch the plumb line that is standing near the wall of the platform and has its plumb directed towards the centre of the disc under it;
-Watch the rotating gyroscope, that has its axis of rotation firmly fixed into one direction;
-Fire a shot of lead at the target across the diameter of the merry-go-round and notice the position of the hole it makes;
-Small pieces of paper are scattered across the water surface in the water basin. The plug is pulled out of the drain and the students observe how the water streams in straight lines towards the drain; the small pieces of paper show the streamlines towards the depression.

Rotating.

The group is standing along the wall at the outside of the platform. The platform is made rotating at full speed. For a short while we rotate with one door open, so the students see that we are rotating, but then we close it and we are in our rotating frame of reference. At full speed it takes us around 5 seconds to make one complete cycle, so this is not too fast, it is still comfortable. (Outside the merry-go-round it has just walking speed: while walking, you can keep up with the merry-go-round.)

Having no sight of the outside world we soon forget that we are rotating, but:

1. Watch the gyroscope! Its frame is rotating! Since we know that a gyroscope has its axis of rotation fixed in space when no external torques are applied. The rotating frame of the gyroscope indicates that we are rotating into the opposite sense.
2. Watching the students you see them leaning towards the centre a little. Make them notice this and show them what the plumb line is doing. Also this plumb line is "leaning"; the plumb is forced outward: centrifugal force.
3. Coriolisforce comes into play when there is movement. So now the students are asked to move around. This is the laughter-part of the session: "Drunken" people walk around.
   Then ask them to observe into which direction they experience a force on their moving body. Soon all will conclude that, when moving forward, there is a force to the left (our merry-go-round rotates clockwise when observed form

above). Also notice that the force is everywhere on the platform and that it doesn't matter into which direction you walk.
Knowing that $F_{Coriolis} = -2m\vec{\omega} \times \vec{v}$, they can check the direction of the force-vector they are experiencing. The negative sign in the formula is relevant! They can also check that the Coriolis force is higher when $\vec{v}$ is higher by trying a speed walk.

4. Now that they "know" by experience what Coriolis force is all about, the students sit down along the outside wall. A basketball is handed to one of them and this person is asked to name somebody facing him and when there is visual contact, to roll the ball towards him. This is the second laughter part of then session, because in spite of there Coriolis-experiences they just had, they usually don't expect the (left-going) curves the ball will make. It takes some time before every try is successful. When they succeed, also throwing the ball can be tried.
5. We tell the next story: "*When the forward rolling ball is continuously deflected to the side, wouldn't it be possible to roll the ball at such a speed that it will return to the one that made it rolling, the ball jus going round in a circle?*" We make them think about it a short while and when they think they have an answer we let them try. Usually it takes a number of endeavours before a successful circle is followed by the ball that rolls along the wall.
Following this we ask what a spectator outside the merry-go-round would see when he looks at the ball (supposing the walls are made of glass). It usually takes some discussion before they realize that the outside spectator sees the ball standing still.
6. We pose the question: "*Into which direction do you have to walk in order that centrifugal force and Coriolis force are opposing each other, and when you think you know the answer, try it!*" After some time everybody walks into the right direction: along the wall, opposite to the rotation of the merry-go-round. Make them notice that they walk easily! They feel no force at all! So probably centrifugal and Coriolis cancel each other. (Centrifugal force is directed away from the centre of the merry-go-round, while Coriolis force is directed towards the centre of the merry-go-round.) Invite them to predict what they will feel when they walk into the other direction: Both forces are pointing outwards, and that can really be felt strongly when doing so!
Make them walk again in the opposing-forces direction and ask them what somebody outside the merry-go-round would see if the walls of the merry-go-round were made of glass. That somebody would see them standing still! While walking, the floor is moving under their feet!
After this experience we shortly discuss the concept of fictitious force: Somebody outside the merry-go-round sees you standing still and his conclusion will be that there is no force acting on you. But you, inside the merry-go-round, need to talk about centrifugal force and Coriolis force opposing each other.
7. Before we fire a shot, we ask the students to predict where the shot will hit the target now, knowing that the bullet has a high speed (150m/sec; the bullet travels in around 0.03 seconds across the diameter of the merry-go-round). They usually predict: to the left of the hole made when standing still, but just a little because the bullet has such a high speed. The fire is shot and to their surprise it is quite a displacement! Knowing $F_{Coriolis} = -2m\vec{\omega} \times \vec{v}$, they can realize that due to the high $\vec{v}$, also $F_{Coriolis}$ is high now.
8. The water-basin is levelled in this rotating situation such that the water is

level with the basin. This is done by removing the two wooden blocks under the two inner legs. When the water is stable, we ask the students what will happen to the streamlines when we pull the plug. Rotation is predicted, but very often into the wrong direction. Discussing the direction of the Coriolis force will make their prediction right.
We pull the plug and see that the water starts streaming in straight lines, but very soon they are bending to the left and move towards the drain in a clockwise rotation. The water leaves the drain very slowly now.

Remarks:

- Do not lean against the wall. The wall is made of very light material and will not withstand a large force.
- We have two opposing doors in our merry-go-round. Since the merry-go-round moves very close to one wall the second door is sometimes needed when we stop the merry-go-round and want to leave it.

Sources:

- Giancoli, D.G., Physics for scientists and engineers with modern physics, pag. 292-294
- McComb,W.D., Dynamics and Relativity, pag. 137-140 and 145