Bike Physics - forces and energy efficiency

Exemplary guiding questions (based on the bicycle context):

Lessons 1+2:

- Why can I be faster on a bike than when I walk/jog? (-> force converter, levers)

(Although I use the same legs and now I have to push even more weight?)

- Why is the same path on the bike much more comfortable than when I run it? (-> Inertia)

Lessons 3+4:

- What is the purpose of the different gears? (-> Laws of leverage, the golden rule of mechanics)

- Why are steep paths easier to walk then to cycle? (-> Decomposition of forces on the inclined plane)

Since the bicycle combines many more mechanical principles, the core topics addressed should have already been covered, otherwise, the bicycle is too overwhelming in complexity along with new subject content. At this point, the topic of forces should be applied to a more complex area and thus deepened.

Curriculum content on the subject of *movement and forces* in Germany (Bavaria, Lower Saxony) - ***Grades 7/8 (age 13/14)***

Main content related to the context:

- *movements under the influence of weight force,*
- *movements under the influence of several forces, addition of forces, reference to frictional forces including air resistance*
- *Equilibrium of forces, theorem of inertia*
- *Decomposition of forces on the inclined plane*

The students ...

- **analyze everyday movements** under the influence of **several force**s and transfer their knowledge of the addition of velocity arrows to the addition of forces. Using the example of **the inclined plane**, they also perform the inverse of this operation with the decomposition of a **force into components** of given directions.
- argue in contexts relevant to everyday life using the **law of inertia** (and the equilibrium of forces). They write short texts with physically conclusive arguments, supported by **meaningful sketches** they have made themselves.
- **describe related phenomena** and attribute them to forces.
- identify forces as the **cause of changes in motion**/deformations or energy changes.
- **represent forces** as directed quantities with the help of **arrows**.
- contrast everyday ideas about movements and their causes with their physical description and, in this context, trace an essential progress in knowledge through the physical view of nature.

PRELIMINARY SCHEDULE

Lesson 1: Sports - Differences between running and cycling.
Objective(s):
- Perform measurements that highlight the difference in efficiency/performance between cycling and running.
- practice independent measurements in sports
- Sports activities: Cycling, sprinting (possibly endurance running?); gain movement experience with bicycles.

Main Content:
- Exercises to compare bike vs. run performance (comparing distance and time values).
- Slow motion recordings of movement processes (for force analysis)
- Viewing video recordings or photos and drawing force arrows

Lesson 2: Physics - Forces during cycling
Objective(s):
- Analyze the motion processes (cycling/running) and explain important differences using force arrows.
- Describe the main forces involved in cycling
- explain the advantages of cycling using the law of inertia (and friction)

Main Content:
- Discuss the drawn force arrows from the 1st lesson, including how the weight force influences the respective type of movement.
(e.g. why by staying still while running you fall down directly, but the bicycle rolls for a long time)
(The example can also be used to show how cycling requires much less force to keep the movement upright).
(- Treat levers only superficially? Becomes more relevant with gear shifting).
- Treat inertia, focusing on speed increase (due to pedaling) and decrease (due to friction /air resistance)

(The 2nd half focuses on a bit more detailed points regarding the bike and a bit more complex content regarding forces - but could still use a better thread)

Lesson 3: Sport - Efficient cycling

Objective(s):

- gather movement experiences with different gears and describe appropriate ways to use them

- perform measurements independently and evaluate the results

Main Content:

- (if possible) ride uphill vs. walk for follow-up discussion at what point steep flats are too strenuous by bike (-> force decomposition follow-up lesson)
- use different gear combinations and investigate advantages/disadvantages (acceleration, top speed, endurance, riding uphill)
- Focus on the corresponding sizes of the discs - if necessary also jack up and look at the number of turns of the rear wheel per pedal revolution (preliminary work to be sensitized for the sports exercises)

Lesson 4: Physics - force transducers and laws of leverage

Objective(s):

- describe in a simplified way the law of leverage using the bicycle as an example

- explain the influence of the different gears in the context of the Golden Rule of Mechanics

- draw the decomposition of forces on the inclined plane using the example of a bicycle and discuss differences to a runner (uphill and downhill)

Main Content:

- Transfer of lever laws to bicycle - analogous to the shaft wheel (https://www.leifiphysik.de/mechanik/einfache-maschinen/grundwissen/wellrad)
- (Golden rule of mechanics) To ride fast (accelerate, top speed), the gear is selected so that the rear wheel makes as many revolutions per pedal stroke as possible (a lot of power over a short distance). For climbs you do it reversed (little power over a long distance).

-> In this context the lesson can also be quickly about work (force times distance in simple cases). One can also draw comparisons to the work (necessary energy) for other means of transport (e.g. in the context of sustainability, comparison with cars and so on).

- At the inclined plane, the additional weight due to the bicycle plays a big role. You can also look at the incline, from when walking is more efficient. (E.g., world record for Mt. Washington is for running and biking about 55 min at 11% average incline).

General thoughts on the rationale for the design:

- The reference needs to be heavily constrained for the children to successfully learn something and not just learn it in a purely superficial way. Since the bicycle combines many more mechanical principles, the core topics addressed should have already been covered, otherwise, the bicycle is too overwhelming in complexity along with new subject content.
- It is usually disadvantageous to use the concepts of energy and force simultaneously in a lesson. Since the processes on the bicycle can be explained primarily with force arrows and lever laws, the word energy is used in as few instances as possible.
- I have narrowed down these topics to
  a) … have a topic as focus, which is treated a lot in school lessons and has a lot of applications at the bicycle, i.e. forces.
  b) … show the students why the bicycle is such an efficient means of transportation (especially to bring the bicycle closer in the context of sustainability)
- Gear shifting is only used in the second half to keep the first half simpler and to be able to hold the lessons separately.

Alternatively, it is possible to look at energy and power. Then one considers the efficiency, friction losses, and the power in total. But then you get primarily into the problem of measurement. Also, the examples are mostly more theoretical (comparisons of values with other means of transport) but it is more difficult to create a synergy effect between sport and physics than when focusing on the individual movement utilizing forces.