Phy-Q: A Testbed for Physical Reasoning - Supplementary Materials

Cheng Xue* **Vimukthini Pinto*** **Chathura Gamage***
Ekaterina Nikonova **Peng Zhang** **Jochen Renz**
School of Computing
The Australian National University
Canberra, Australia
{cheng.xue, vimukthini.inguruwattage, chathura.gamage}@anu.edu.au
{ekaterina.nikonova, p.zhang, jochen.renz}@anu.edu.au

A The Objects in Phy-Q Tasks

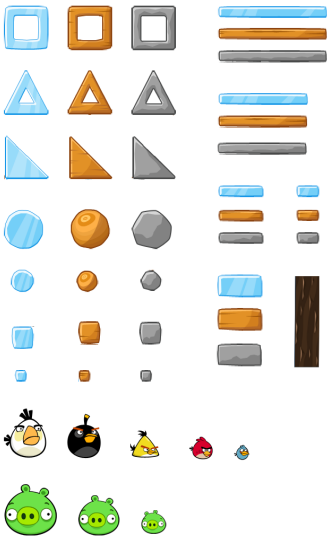


Figure 1: Objects that appear in the Phy-Q tasks. The shape and the size of the objects are fixed, except the platform object (dark brown) that can appear in different shapes and sizes.

Table 1: Powers of the birds in the tasks. The birds with powers are used only for the tasks in the manoeuvring scenario. The powers can be activated by tapping the bird in the flight.

Bird	Power
Red bird	No power
Yellow bird	Accelerates forward
Blue bird	Splits into three birds
White bird	Drops an explosive egg
Black bird	Explodes itself

*Equal contribution

Preprint. Under review.

B Phy-Q Tasks

B.1 Task Templates in Phy-Q

Phy-Q contains 75 task templates for 15 physical scenarios. The figures 2 to 16 show the task templates of the 15 scenarios: single force, multiple forces, rolling, falling, sliding, bouncing, relative weight, relative height, relative width, shape difference, non-greedy actions, structural analysis, clearing paths, adequate timing, and manoeuvring respectively. Figure 17 shows the tasks generated from six example task templates.

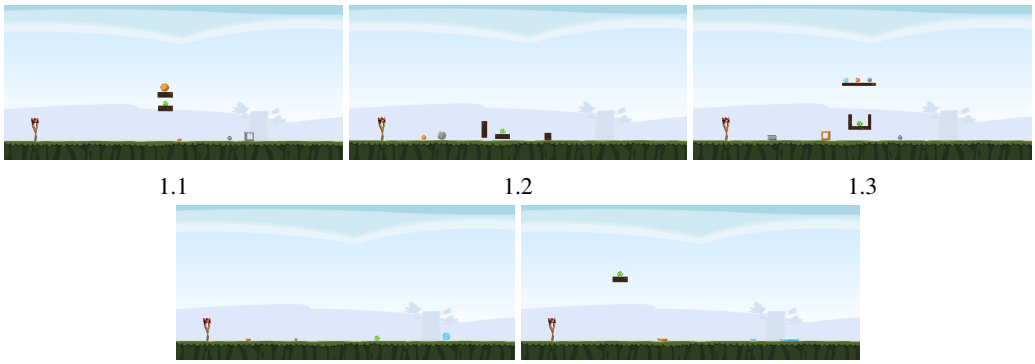


Figure 2: Task templates from the single force scenario. The pig in these templates can be destroyed by directly shooting the bird at the pig.

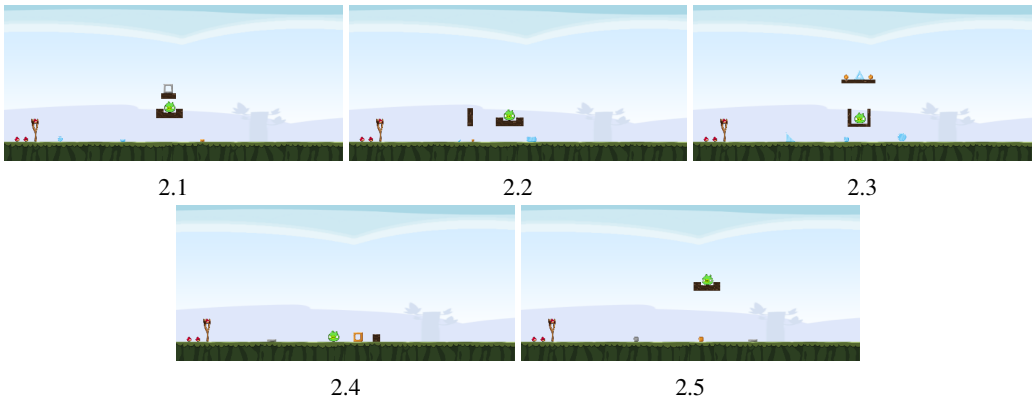


Figure 3: Task templates from the multiple forces scenario. The pig in these templates can be destroyed by shooting multiple birds at the pig.

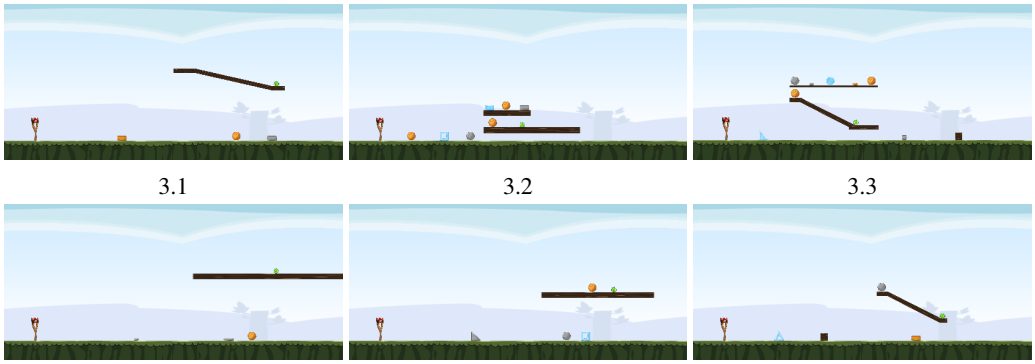


Figure 4: Task templates from the rolling scenario. The pig in these templates can be destroyed by rolling the correct circular block into the pig or rolling the bird itself.

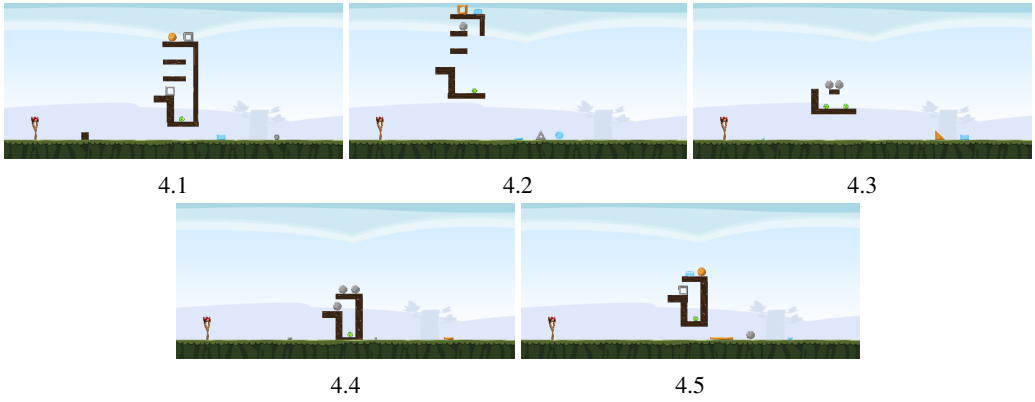


Figure 5: Task templates from the falling scenario. The pig in these templates can be destroyed by falling the correct block onto the pig.

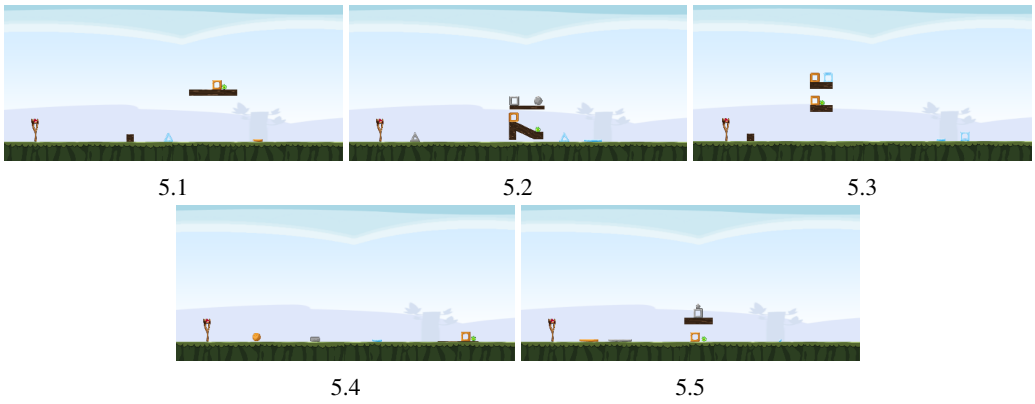
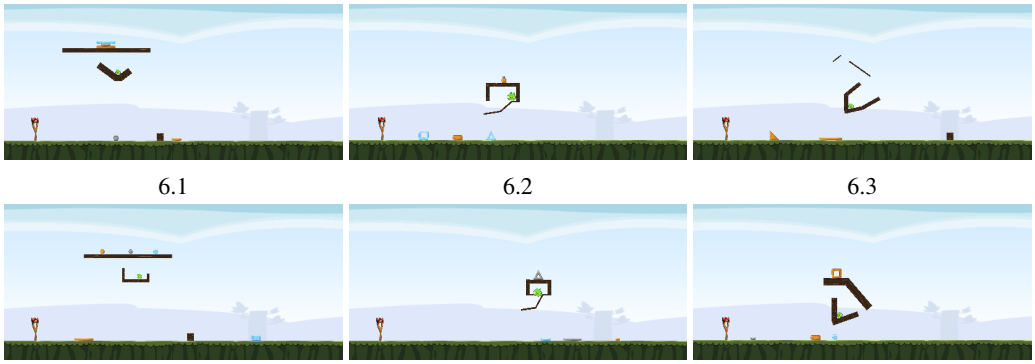


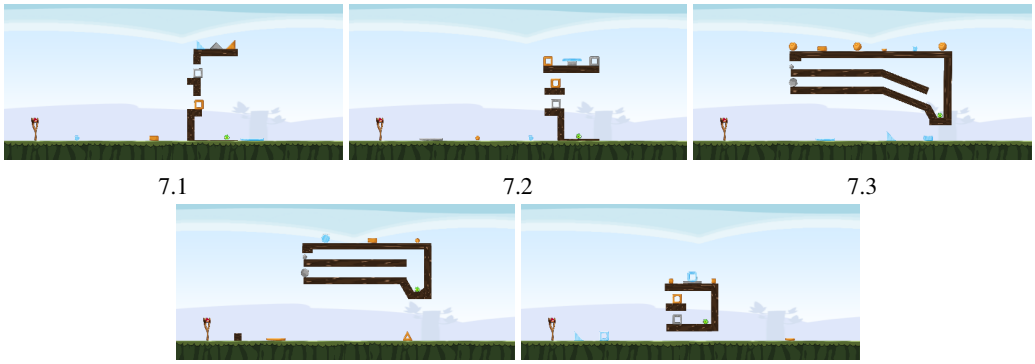
Figure 6: Task templates from the sliding scenario. The pig in these templates can be destroyed by sliding the correct block into the pig.



6.1 6.2 6.3

6.4 6.5 6.6

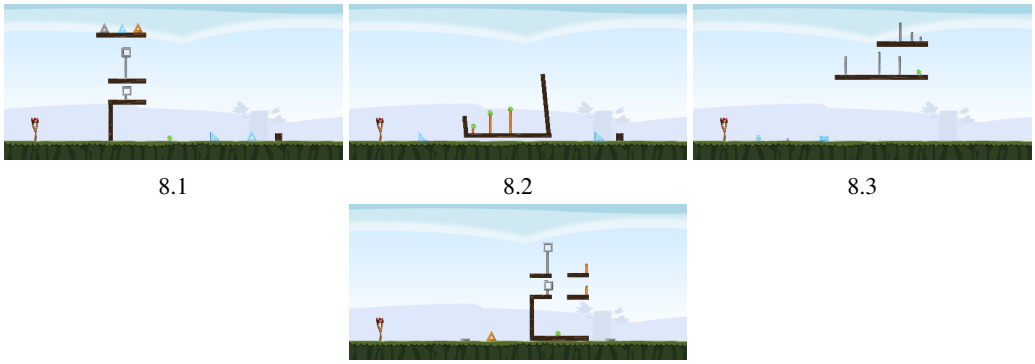
Figure 7: Task templates from the bouncing scenario. The pig in these templates can be destroyed by bouncing the bird off the platforms onto the pig.



7.1 7.2 7.3

7.4 7.5

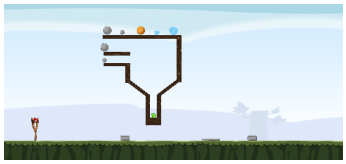
Figure 8: Task templates from the relative weight scenario. The pig in these templates can be destroyed by shooting the bird at the block with correct weight such that the block moves and collides with the pig.



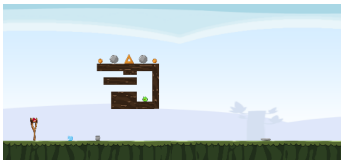
8.1 8.2 8.3

8.4

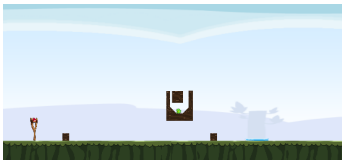
Figure 9: Task templates from the relative height scenario. The pig in these templates can be destroyed by shooting the bird at the block with correct height or at the block located in correct height such that the blocks move and collide with the pig.



9.1



9.2

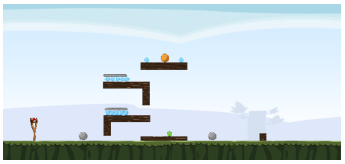


9.3

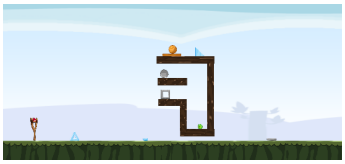
9.4

Figure 10: Task templates from the relative width scenario. The pig in these templates can be destroyed by shooting the bird at the block with correct width or using the bird itself to squeeze through the opening that it can fit and collide with the pig.

10.1



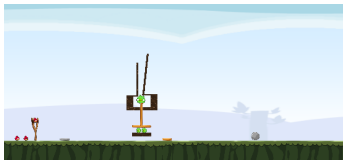
10.2



10.3

10.4

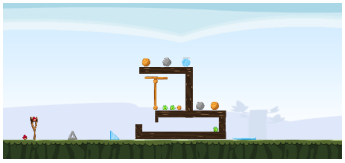
Figure 11: Task templates from the shape difference scenario. The pig in these templates can be destroyed by shooting the bird considering the consequences of the shot due to the effect of the differences of the objects' shapes.



11.1

11.2

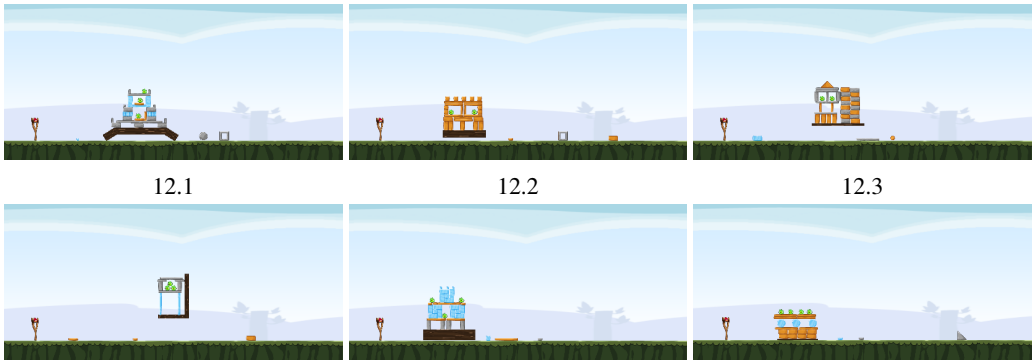
11.3



11.4

11.5

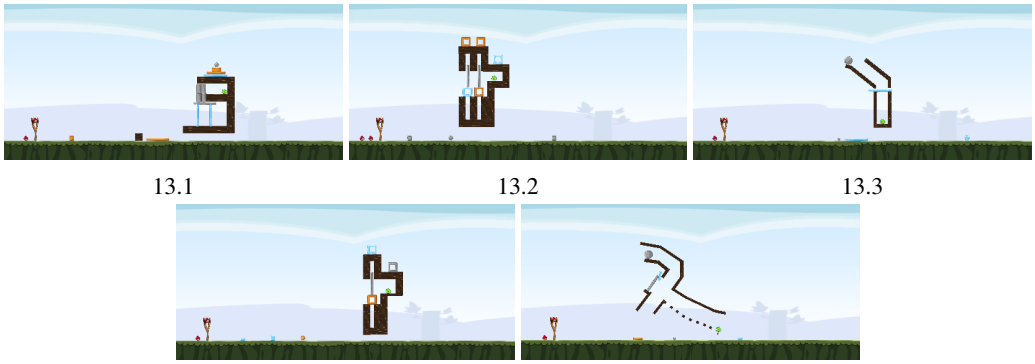
Figure 12: Task templates from the non-greedy actions scenario. A greedy action in Angry Birds can be considered as the action that kills a higher number of pigs. In these templates, the non-greedy action needs to be done first since the level becomes unsolvable if the greedy action is done first.



12.1 12.2 12.3

12.4 12.5 12.6

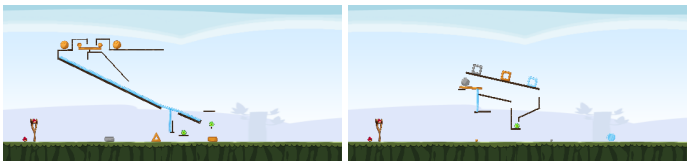
Figure 13: Task templates from the structural analysis scenario. The pigs in these templates can be destroyed by shooting the bird at correct position of the physical structure to break its stability and collapse.



13.1 13.2 13.3

13.4 13.5

Figure 14: Task templates from the clearing paths scenario. In these templates, the path to reach the pig needs to be cleared/created first and then destroy the pig.



14.1 14.2

Figure 15: Task templates from the adequate timing scenario. In these templates, after doing the first bird shot, the second bird is needed to shoot within a time frame such that all the pigs can be destroyed.

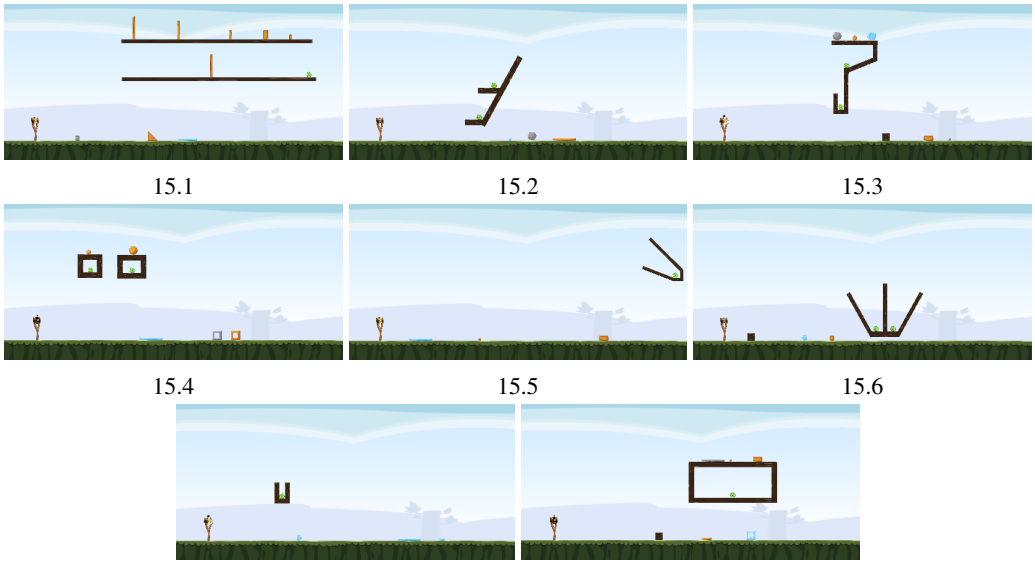


Figure 16: Task templates from the manoeuvring scenario. The pigs in these templates can be destroyed by correctly manoeuvring the birds by activating their powers in the flight.

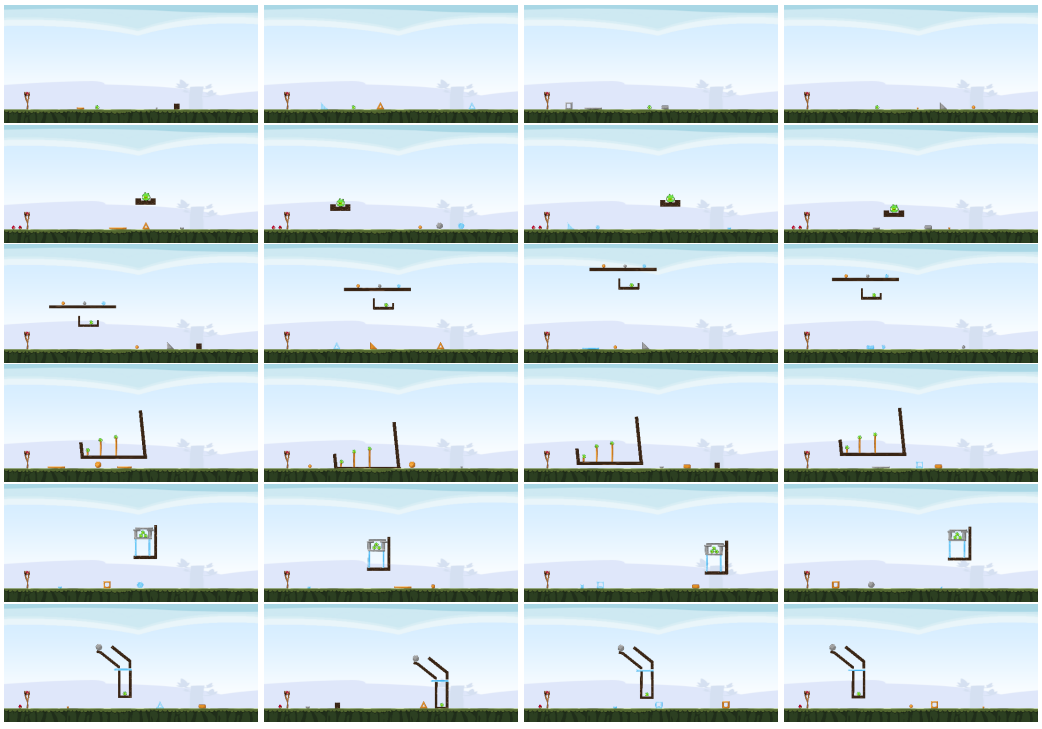


Figure 17: Each row shows four example tasks generated from the same task template. The positions of the objects and the distraction objects vary within the tasks of the same template, therefore each task has its own solution; however all tasks of the same template can be solved by the same physical rule.

B.2 Differences Between the Task Templates in Phy-Q

Table 2: The differences between the task templates of the scenarios from 1 to 9 are presented using the high-level solution descriptions of the task templates.

Scenario	Description
1. Single force	1.1 Applying a single force using the lower trajectory of the bird. 1.2 Applying a single force using the higher trajectory of the bird. 1.3 Applying a single adequate force using a specific stretch of the slingshot. 1.4 Applying a single force to the pig on the ground by using either lower or higher trajectory of the bird. 1.5 Applying a single force to the pig on the platform by using either lower or higher trajectory of the bird.
2. Multiple forces	2.1 Applying multiple forces using the lower trajectory of the bird. 2.2 Applying multiple forces using the higher trajectory of the bird. 2.3 Applying multiple adequate forces using a specific stretch of the slingshot. 2.4 Applying multiple forces to the pig on the ground by using either lower or higher trajectory of the bird. 2.5 Applying a multiple forces to the pig on the platform by using either lower or higher trajectory of the bird.
3. Rolling	3.1 Rolling the bird down a ramp into the directly-unreachable pig. 3.2 Rolling the circular object on a flat surface into the path-blocked pig. 3.3 Rolling the circular object down a ramp into the path-blocked pig. 3.4 Rolling the bird in a flat surface into the directly-unreachable pig. 3.5 Rolling the circular object into the directly-unreachable pig. 3.6 Rolling the circular object down a ramp into the directly-unreachable pig.
4. Falling	4.1 Falling the square block choosing correct path onto the pig. 4.2 Falling the circular block choosing correct path on to the pig. 4.3 Falling the two circular blocks on to the two pigs. 4.4 Falling the circular block onto the pig. 4.5 Falling the square block onto the pig.
5. Sliding	5.1 Sliding the block on a flat surface into the unreachable pig. 5.2 Sliding the block down a ramp into the path-blocked pig. 5.3 Sliding the block on a flat surface into the path-blocked pig. 5.4 Sliding the block on ground into the unreachable pig. 5.5 Sliding the block on ground into the path-blocked pig.
6. Bouncing	6.1 Bouncing the bird off a flat surface onto the pig in a inclined plane. 6.2 Bouncing the bird upwards by smashing the bird on a lower surface to reach the pig. 6.3 Bouncing the bird off an inclined surface onto the pig in the pouch. 6.4 Bouncing the bird off a flat surface onto the pig on a flat surface. 6.5 Bouncing the bird upwards by smashing the bird on a lower surface to reach the big pig. 6.6 Bouncing the bird off an inclined surface onto the pig in a inclined plane.
7. Relative weight	7.1 Falling the correct block (below block) to fall onto the pig considering the weight. 7.2 Falling the correct block (above block) to fall onto the pig considering the weight. 7.3 Rolling the small circular block with less weight on a flat surface and on an incline surface to reach the pig. 7.4 Rolling the small circular block with less weight on a flat surface to reach the pig. 7.5 Sliding and falling the brown coloured block on to the pig considering the weight.
8. Relative height	8.1 Toppling the square block on the taller block onto the pig. 8.2 Bouncing the bird to hit the tallest block in order to create a domino effect. 8.3 Shooting the tallest block to create a domino effect to reach the pig. 8.4 Falling the square block on the short block onto the pig.
9. Relative width	9.1 Falling the small circular block which can go through the slit. 9.2 Shooting the bird using lower trajectory at the lower opening which is wider to squeeze the bird through it. 9.3 Shooting the bird using the higher trajectory at the wider opening to fall into it. 9.4 Shooting the bird using lower trajectory at the higher opening which is wider to squeeze the bird through it.

Table 3: The differences between the task templates of the scenarios from 10 to 15 are presented using the high-level solution descriptions of the task templates.

Scenario	Description
10. Shape difference	10.1 Shooting at the triangular block instead of the circular block, so that edges of the triangle can reach the pig. 10.2 Shooting at the circular block supporter (instead of the square block supporter) which can make the rectangular block to roll and fall on the pig. 10.3 Shooting at the circular block (instead of the square block) which can roll and fall on the pig. 10.4 Shooting at the triangular block supporter (instead of the square block supporter) which enables the circular object to roll on to the pig.
11. Non-greedy actions	11.1 Using the first two birds to destroy the larger pig (non-greedy action) and shooting the last bird to destroy the two pigs. 11.2 Shooting the first bird to destroy the pig in the front (non-greedy action) before destroying the two pigs. 11.3 Taking the non-greedy action first by shooting at the basket with one pig before shooting at the two pigs. 11.4 Taking the non-greedy action first by targeting the tunnel with a single pig before shooting at the location with two pigs. 11.5 Taking the non-greedy action first to destroy the pig inside the basket before shooting the two pigs on top.
12. Structural analysis	12.1 - 12.6 Shooting at the correct position to break the stability and destroy the pigs based on the given structure.
13. Clearing paths	13.1 Shooting the first bird to destroy the supporting blocks to clear the path to the pig. 13.2 Shooting the first two birds to fall the path-blocking blocks into the slits. 13.3 Shooting at the the blocking-block to clear the path for the circular block to reach the pig. 13.4 Shooting the first bird to fall the path-blocking block into the slit. 13.5 Using the first bird to fall the block to create a path to reach the pig.
14. Adequate timing	14.1 Shooting the second bird at the correct time after the two balls on top moves down the ramp. 14.2 Shooting the second bird at the correct time before the circular block blocks the path to the pig.
15. Manoeuvring	15.1 Tapping the yellow bird before reaching the wood block to reach the pig. 15.2 Tapping the blue bird before reaching the pig on the top to make sure two child blue birds reach the two pigs. 15.3 Tapping the white bird to ensure the egg reaches the lower pig and bird reaches the upper pig. 15.4 Tapping the black bird to cause an explosion that affects both pigs. 15.5 Tapping the yellow bird to reach the unreachable pig. 15.6 Tapping the blue bird to ensure child birds fall to the two separate baskets with pigs. 15.7 Tapping the white bird to ensure the egg falls onto the pig. 15.8 Tapping the black bird closer to the covered pig.

B.3 Solution Descriptions for Example Task Templates in Phy-Q

Table 4 shows solution descriptions for 15 example task templates in Phy-Q representing one from each 15 physical scenarios.

Table 4: Solution descriptions for 15 example task templates in Phy-Q.

Task template	Solution description
1.4	Single force: A single force is needed to be applied to the pig to destroy it by a direct bird shot.
2.5	Multiple forces: Multiple forces are needed to be applied to destroy the pig by multiple bird shots.
3.6	Rolling: The circular object is needed to be rolled onto the pig, which is unreachable for the bird from the slingshot, causing the pig to be destroyed.
4.4	Falling: The circular object is needed to be fallen onto the pig causing the pig to be destroyed.
5.1	Sliding: The square object is needed to be slid to hit the pig, which is unreachable for the bird from the slingshot, causing the pig to be destroyed.
6.1	Bouncing: The bird is needed to be bounced off the platform (dark-brown object) to hit and destroy the pig.
7.3	Relative weight: The small circular block is lighter than the big circular block. Out of the two blocks, the small circular block can only be rolled to reach the pig and destroy.
8.4	Relative height: The square block on top of the taller rectangular block will not fall through the gap due to the height of the rectangular block. Hence the square block on top of the shorter rectangular block needs to be toppled to fall through the gap and destroy the pig.
9.4	Relative width: The bird cannot go through the lower entrance which has a narrow opening. Hence the bird is needed to be shot to the upper entrance to reach the pig and destroy it.
10.4	Shape difference: The circular block on two triangle blocks can be rolled down by breaking a one triangle block and the circular block on two square blocks cannot be rolled down by breaking a one square block. Hence, the triangle block needs to be destroyed to make the circular block roll and fall onto the pig causing the pig to be destroyed.
11.5	Non-greedy actions: A greedy action tries to destroy the highest number of pigs in a single bird shot. If the two pigs resting on the circular block are destroyed, then the circular block will roll down and block the entrance to reach the below pig. Hence, the below pig is needed to be destroyed first and then the upper two pigs.
12.3	Structural analysis: The bird is needed to be shot at the weak point of the structure to break the stability and destroy the pigs. Shooting elsewhere does not destroy the two pigs with a single bird shot.
13.5	Clearing paths: First, the rectangle block is needed to be positioned correctly to open the path for the circular block to reach the pig. Then the circular block is needed to be rolled to destroy the pig.
14.4	Adequate timing: First, the two circular objects are needed to be rolled to the ramp. Then, after the first circle passes the prop and before the second circle reaches the prop, the prop needs to be destroyed to make the second circle fall onto the lower pig.
15.6	Manoeuvring: The blue bird splits into three other birds when it is tapped in the flight. The blue bird is needed to be tapped at the correct position to manoeuvre the birds to reach the two separated pigs.

C Within Template Evaluation Results

Figure 18 shows the passing rate of the nine baseline agents for the 75 task templates for the *within template evaluation*. The within template evaluation measures the local generalization ability of an agent. For learning agents, we take the first 80 tasks from each task template as the training set and the last 20 tasks to evaluate the local generalization ability of the agent. As there is no training phase for heuristic agents, the heuristic agents are evaluated on the 20 test task templates. Due to the randomness in the heuristic agents, we give 5 attempts in each task and take the average the pass rate of the task. Presented in Figure 18 is the average pass rate of all test tasks. Overall, it can be seen that learning agents perform better in the within template evaluation.

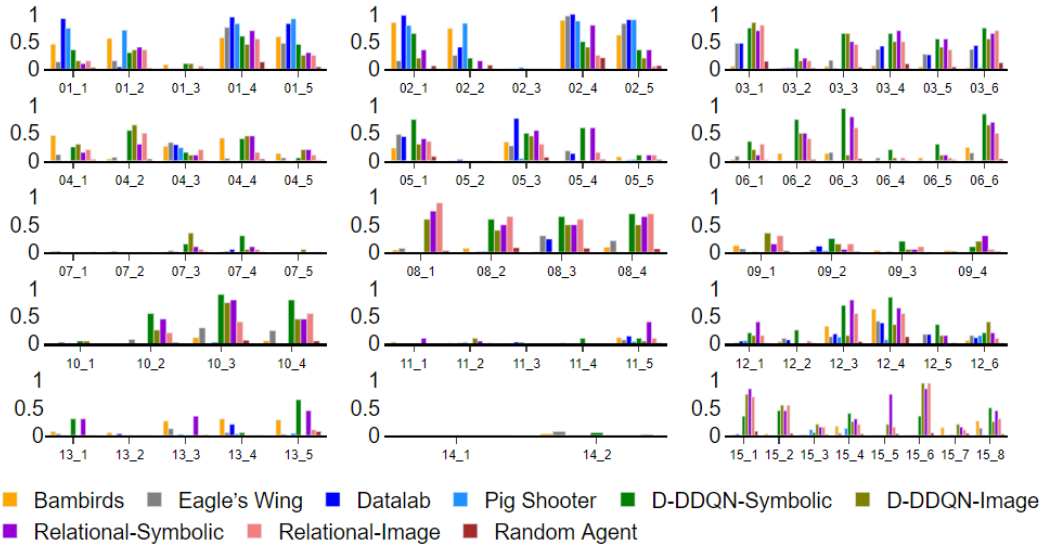


Figure 18: Passing rates of the agents for the *within template evaluation*. The results are presented for the 75 task templates by separating them into the 15 physical scenarios (1. single force, 2. multiple forces, 3. rolling, 4. falling, 5. sliding, 6. bouncing, 7. relative weight, 8. relative height, 9. relative width, 10. shape difference, 11. non-greedy actions, 12. structural analysis, 13. clearing paths, 14. adequate timing, and 15. manoeuvring). The x-axis is the index of the task template (x_y represents the y^{th} task template of the x^{th} physical scenario) and y-axis is the passing rate.

D Within Scenario Evaluation Training and Testing Split

Within scenario evaluation measures the broad generalization of an agent. Agent trains on a subset of task templates within a specific scenario and is evaluated on the rest of the task templates in the same scenario. Table 5 shows the division of task templates for training and testing in the *within scenario evaluation* for the 15 physical scenarios.

Table 5: The train-test split of the task templates for the *within scenario evaluation*

Scenario	Training templates	Testing templates
1. Single force	1.1, 1.2, 1.3	1.4, 1.5
2. Multiple forces	2.1, 2.2, 2.3	2.4, 2.5
3. Rolling	3.1, 3.2, 3.3	3.4, 3.5, 3.6
4. Falling	4.1, 4.2, 4.3	4.4, 4.5
5. Sliding	5.1, 5.2, 5.3	5.4, 5.5
6. Bouncing	6.1, 6.2, 6.3	6.4, 6.5, 6.6
7. Relative weight	7.1, 7.2, 7.3	7.4, 7.5
8. Relative height	8.1, 8.2	8.3, 8.4
9. Relative width	9.1, 9.2	9.3, 9.4
10. Shape difference	10.1, 10.2	10.3, 10.4
11. Non-greedy actions	11.1, 11.2, 11.3	11.4, 11.5
12. Structural analysis	12.1, 12.2, 12.3	12.4, 12.5, 12.6
13. Clearing paths	13.1, 13.2, 13.3	13.4, 13.5
14. Adequate timing	14.1	14.2
15. Manoeuvring	15.1, 15.2, 15.3, 15.4	15.5, 15.6, 15.7, 15.8

E Human Player Evaluation

Figure 19 presents the average pass rate, the pass rate the player achieved within five attempts, the maximum number of attempts made, and the total thinking time taken (in seconds) by human participants for the 15 capabilities. Figure 20 presents the performance of human participants, performance of heuristic agents, and local generalization of learning agents on the exact task templates used for the human player evaluation to make a direct comparison of agents with human performance. We used the average pass rates of the humans (e.g., if the player passes in the first attempt, pass rate 100% and if the player passes in the fifth attempt the pass rate is 20%) to have a fair comparison with the agents. We illustrate the five attempt pass rate to show that almost all the human players could pass the tasks within five attempts.

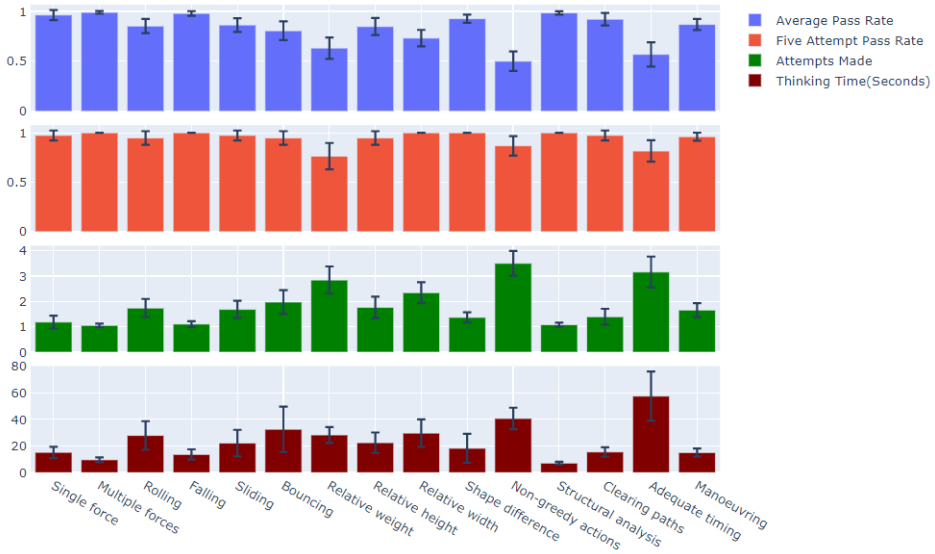


Figure 19: The average pass rate, five attempt pass rate, maximum number of attempts made, and the total thinking time taken by human participants (in seconds) for the 15 physical scenarios. Error bars represent the 95% confidence interval.

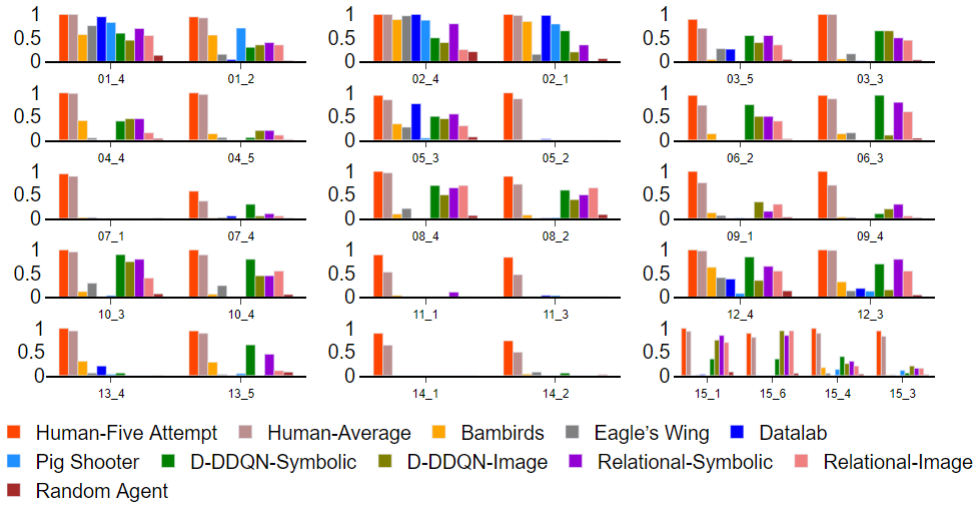


Figure 20: Performance of humans, performance of heuristic agents, and local generalization of learning agents on the sample of task templates used for the human evaluation. It can be seen that overall human performance is far ahead of agents.

F 2021 AIBIRDS Competition Game Levels Used for the Evaluation

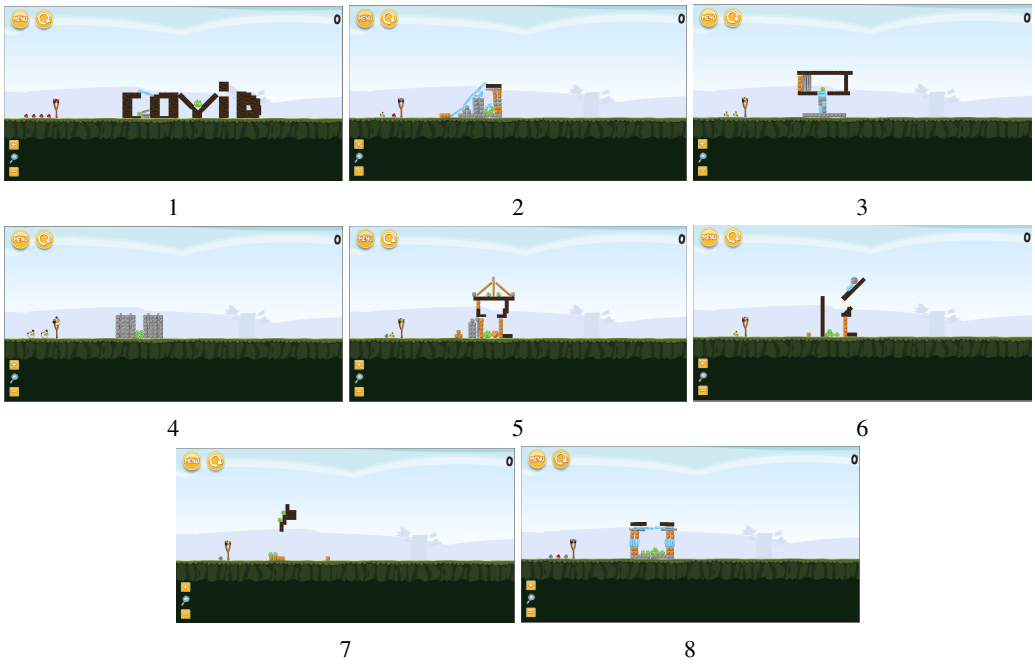


Figure 21: The game levels from the 2021 AIBIRDS competition used for the AIBIRDS heuristic agent evaluation. The game levels were selected by excluding the ones with cartoon effects.

G Computing Resources Used for the Experiments

We used computing resources from Amazon AWS to run the evaluations. Four instances of vCPUs with 2.5 GHz processors and 16 GB memory were used. NVIDIA T4 GPUs with 16 GB memory were used in those instances.