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Geneticus Investigatio: A Classroom-Based Technology-Enhanced Learning Environment for Problem-Solving Process Skills in Genetics

Anurag DEEP[a*], Sahana MURTHY* & Jayadeva BHAT*
[*]*Indian Institute of Technology Bombay, India*
[a]anuragdeep4949@iitb.ac.in

Abstract: Solving problems in science domains requires learners to integrate concepts across topics, along with problem-solving and inquiry process skills. The complexity of these concepts and skills becomes manifold at the tertiary undergraduate level, and are known to be challenging for learners. To support learners in this process, we have designed and developed Geneticus Investigatio (GI), a technology-enhanced learning environment for semi-structured problems in the context of Mendelian genetics. GI facilitates the integration of concepts and problem-solving process skills, through inquiry-based learning activities interspersed with evaluative question prompts and reflective activities. GI is developed using Google sites and H5P as a web-based learning environment to provide easy access to learners and to enable teachers to adapt the learning activities to different topics. In this paper, we present the theoretical basis and design of GI. We report a quasi-experimental classroom study (N=63) in which we investigated learning of problem-solving skills and perceptions of usability and usefulness of GI. The results indicate higher learning gains of problem-solving process skills with GI, and learner perceptions that certain activities in GI are helpful for learning concepts and process skills.

Keywords: Problem-solving process skill, Question Prompts, Mendelian Genetics

1. Introduction

Problem-solving is an integral part of the undergraduate science curriculum in various topics. These problems can range from well-structured to ill-structured (Fernandes & Simon, 1999). An in-between type is a semi-structured type of problem, in which students are required to connect concepts across topics and use a variety of problem solving and inquiry skills. Such problems are common in genetics, which is a compulsory foundational course of undergraduate bioscience and medical learners. In these problems, learners are required to identify and justify the patterns of inheritance behind various biological phenomena. These problems may follow various theoretical frameworks such as Mendelian or non-Mendelian inheritance patterns, and encompass a variety of concepts related to the breeding context of plants and animals. In addition to identifying and applying appropriate theories and concepts, such problems require the formulation of hypotheses, identification of variables, making predictions and testing predicted outcomes against the experimental ones. Thus a learner has to simultaneously work with concepts across multiple topics, problem-solving skills, and inquiry skills. Experts solve these kinds of problems by addressing all these complexities, starting with analyzing the problem in parts and generating a possible hypothesis for an explanation. This is followed by designing the experiment, interpreting the results according to the theoretical framework and the hypothesis. The difference between expected and observed results is calculated using statistical or other methods, based on which a decision is to be made as to whether the results are acceptable or not. This process is often unclear to novice learners, especially why these steps are required (Kim & Hannafin, 2011), leading to mechanical application of the problem-solving steps (Karagoz & Cakir 2011). Thus, learners need to explicitly learn problem-solving skills within the context of genetics experiments and integrate them along with the relevant theoretical concepts.

Research suggests utilizing the affordances of the technology-enhanced learning (TEL) environments in developing these skills by providing overall structure to the learning activities, immediate and personalized feedback, reflective question prompts, and so on. Several inquiry-based learning environments focus on developing such skills, for example, WISE (Slotta 2002), Geniverse

(Concord consortium 2010). Most of these TEL environments are for topics in high-school and middle school science.

Our proposed TEL environment Geneticus Investigatio (GI) is designed for college-level biology undergraduates with a focus on the solving problems by applying genetics concepts, understanding of basics of statistics with integrated science process skills. GI emphasizes integration of concepts across the required topics, along with reflective and evaluative question prompts and scaffolds. These question prompts engage learners in the understanding of concepts across the multiple topics to solve the problem, and on reflection of actions performed while doing the learning activities. Through the learning activities in GI, learners perform steps of problem-solving like identifying hypotheses, designing of experiments, comparing predicted and observed results, and accepting or rejecting the hypothesis.

One design consideration in the development of GI was to make it easily accessible to learners in college classrooms, and to make it adaptable to different topics if instructors wished to add or edit content, learning activities or problems in other topics. GI has thus been developed using Google sites and H5P (Jouble, 2013) as a web-based learning environment which is known to be convenient to access digital content by students and teachers alike (Yin et al., 2017). GI is browser based and works on laptops, tablets, or mobile phones. Students can use it easily in classroom settings or anywhere else and only need a device and wireless connection, and teachers can adapt it quickly since it does not require advance computer knowledge.

In this paper, we describe the theoretical basis and design of GI, and report a quasi-experimental classroom study with 63 undergraduate bioscience learners in the context of Mendelian genetics. The two research questions which were the focus of this study are:

- Do students who interact with GI develop problem-solving process skills?
- What are user perceptions of usability and usefulness of GI?

2. Background Research

One of the principal goals of science education has been training learners in solving problems of various types. Researchers and theorists have made remarkable progress in identifying and characterizing problem solving. Some of them include identifying students' difficulties in diverse contexts, proposing problem-solving phases, and associated learning activities (Xun & Land 2004). A variation of this problem-solving activity includes hypothesis generation, testing, and revision. This variation is essential in the context of understanding or doing science by the learners, which is the core practice in science education. It helps in establishing the feasibility/correctness of a hypothesis, eliminate candidate hypothesis/set of results, and compare predicted/observed results. It also allows learners to develop an in-depth understanding of the subject (Cooper, Hanmer, & Cerbin, 2006).

Decades of research into science inquiry learning has given us insights into nature of learning and challenges, design of learning environments to support students (Bransford, Brown, & Cocking, 2000), and guidelines and principles for scaffolds (Quintana et al, 2004). Affordances of TEL environments have been used to develop scientific inquiry skills similar to problem-solving skills. Among them are WISE (Slotta 2002), Go-Labs (Jong et. al. 2014), Apple Tree (Chen et al. 2013), and Geniverse (Concord consortium 2010). These environments are to be used either online or can be downloaded. Most of this research has been in topics for the middle and high school levels.

In undergraduate science learning, a significant difficulty that has been reported in genetics problem-solving is rote application of problem-solving process steps without a comprehensive conceptual understanding of these steps (Karagoz & Cakir 2011). In typical undergraduate curricula, students encounter the required concepts and skills for solving such problems across across different courses, for example, knowledge of genetics concepts in a basic or advanced genetics course, concepts of statistics in their bio-statistics course and application of process skills in practical labs. Thus students lack an integrated perspective while solving problems. So there is a need for developing learners' problem-solving skills, especially for open problems. This skill is especially crucial for undergraduate bio-science learners in the context of genetics as it deals with multiple underlying reasons for a biological observation. To pinpoint the specific reason, learners have to generate, test, and revise the hypothesis. An example from the context of genetics is that learners are required to identify and justify the patterns of inheritance behind various biological phenomena. To identify these inheritance patterns, they have to solve problems which are either cause-effect problems (closed problems) or effect-cause problems (open problems) (Orcajo & Aznar 2005).

Solving such open-ended problems becomes a daunting task for them. They require scaffolds at various places during the problem-solving process. These scaffolds can be in the form of feedback, access to domain concepts, etc. An example of feedback could be in the way of guiding questions for reflection or identification of possible mistakes. To do that, technology affordances is widely used. Some of the existing learning environments which meet some of these requirements are Genetics with Jean (Thompson & McGill 2017) an affective tutoring system to teach the concepts of genetics. Another case-based laboratory simulation was built for learning core concepts and skills in medical genetics (Makransky et al. 2016). Some of the interactive affordance from these environments could meet our need for the learning environment. But there is a need of affordances that could help in providing overall structure to the sequence of learning activities along with dynamic and personalized feedback in various forms. An example of this is reflective question prompts for evaluating conceptual understanding while watching an interactive video. Another example is the interactive learning activities like drag and drop activity to engage learners while interacting with the content.

3. *Geneticus Investigatio:* A Problem-solving Learning Environment for Genetics

The pedagogical basis of GI gets inputs from guidelines in existing research in inquiry learning and problem solving, as well as from interviews we conducted with instructors teaching undergraduate level genetics. In literature, it has been documented that students have difficulties in identifying parts of the hypothesis, designing experiments, predicting the result and concluding about the hypothesis. Besides these, various topics in genetics, especially the topic of Mendelian genetics was perceived to be difficult by the students (Bahar 1999). We conducted a study with the undergraduate instructors where they solved an open-ended problem related to Mendelian genetics. They validated known students' difficulties. Besides this, the integration of concepts of genetics, statistical methods, and science process skills was also stated as difficult for the students. So there was a need to facilitate the integration of principles and concepts from multiple topics along with problem-solving skills, experimental abilities, and statistical methods.

A preliminary version of GI was developed earlier, which was primarily based on agent-based modeling and simulations (Deep, Murthy & Bhat 2016). In this environment, learners identified properties and behaviors of agents along with identifying rules governing the interaction between these agents. They then executed their model and compared their output with that of the expert model. A pilot study with this version of GI revealed that learners had difficulty in identifying the dependent and independent variable and designing a suitable experiment to test the hypothesis. Besides these, they were not able to make reasoned predictions which needed significant application of concepts of genetics along with understanding of concepts of statistics like Chi-square test, degree of freedom, calculating and comparing chi-square value with the critical value. These and other limitations necessitated the need for a revised version of GI which contained stronger supports for students, and a more accessible way for teachers to include the supports in the learning environment.

Figure 1 shows the key features of the GI. The overall sequence of learning activities in GI for the integration of domain, process skills, and statistics has been adapted from the steps of inquiry learning (Pedaste et al., 2015). These activities are interspersed with evaluative and reflective prompts for promoting metacognition during problem-solving (Xun & Land 2004). GI also require the learners to arrange the sequence of activities for experimenting as done in an authentic scenario.

3.1 Pedagogical Design and Learning Activities

The overall pedagogy of the revised version of GI contained learning activities focused on integration, and evaluative question prompts. An essential aspect was the reflective summarising activity along with scaffolds. They helped in implementing the following:

- *Integration of domain concepts, problem-solving process skills and statistical tools:*

It provided the overall structure to the learning environment and ensured that students should be able to integrate process skills along with the knowledge of genetics and statistics. Students began by defining the problem and identifying a suitable hypothesis to test (Pedaste et al., 2015). It requires the learner to understand the context, for example, the scientific phenomenon which is to be explained. To explain the context, he/she select a hypothesis from the given set of hypotheses. In this, learning activities requires students to state the reason behind the selection of a particular hypothesis, state the assumptions they will make while testing this hypothesis along with declaring the dependent and independent variable. The system displays hypothesis and drag and drop activity for identifying the variables (Figure 2).

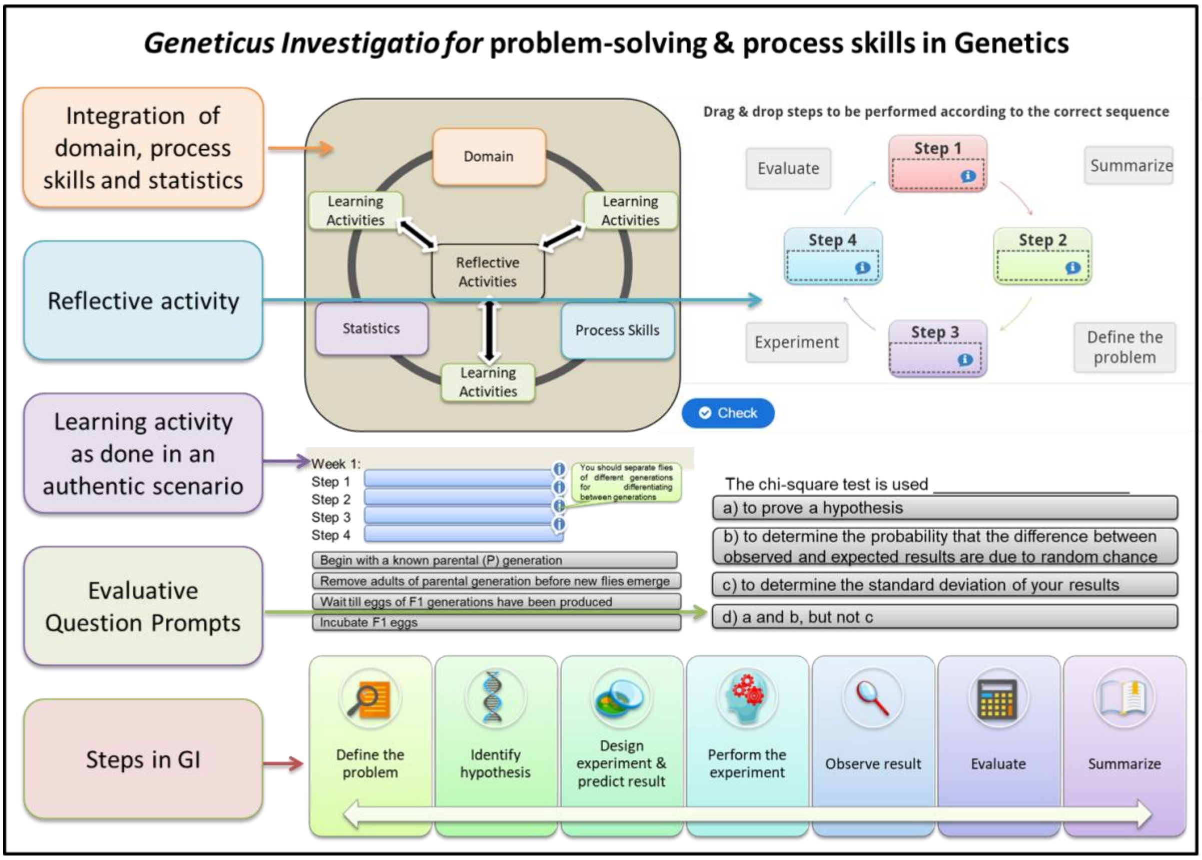

Figure 1. Key features of *Genetics Investigatio*

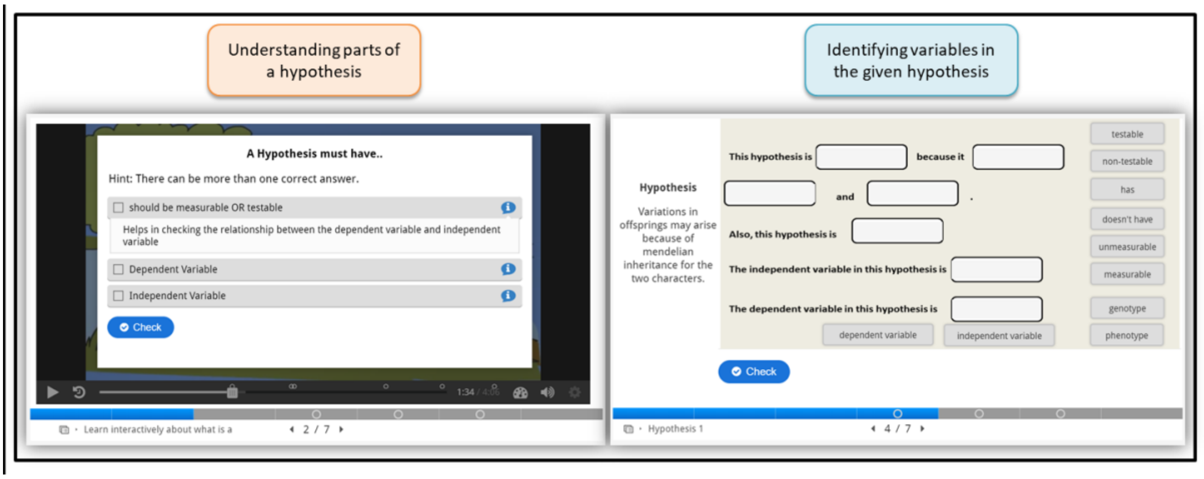

Figure 2. Learning activities in *GI for selecting hypothesis*

It was followed by the step of testing hypothesis, which included designing an experiment and reasoning from the hypothesis to predict the result. In this, learning activities requires learners to decide about the cross made, design the steps of breeding experiment, and calculate the predicted value (Figure 3). The system displays activities related to determining the cross made and calculating the ratio by providing editing boxes. These editing boxes are for stating laws of inheritance, creating Punnette square and the calculating ratio of offspring. Besides this, learners interactively design steps of breeding experiments and watch a lab demo video of an actual experiment done in practical labs.

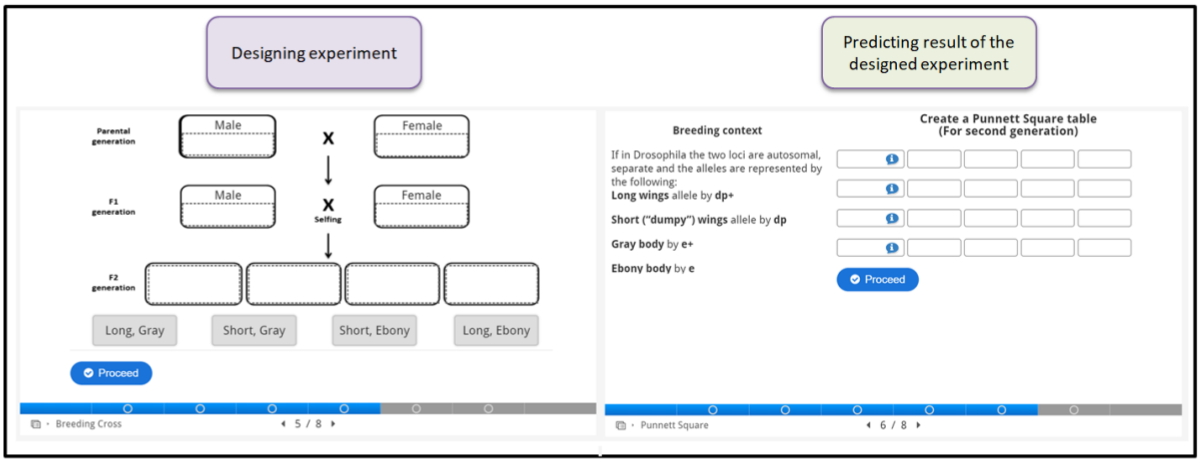

Figure 3. Learning activities in *GI for testing hypothesis*

The last step was to revise the hypothesis if required by comparing the result of the expected and observed values. The last learning objective has two goals, namely "Evaluating" and "Summarizing." Once the experiment is designed, and results are collected, it has to be statistically compared with the predicted outcome and come to a conclusion. In the evaluate phase, learners learn interactively about the Chi-square test, calculate the Chi-Square value, compare it with the critical value, and conclude based on critical value (Figure 4). The system displays interactive video which has reflective question prompts related to what, why, and how of chi-square and calculate the chi-square value by providing the functionality of editing boxes. Besides this learner reflect on the steps to be done while solving similar problems through the drag and drop activity.

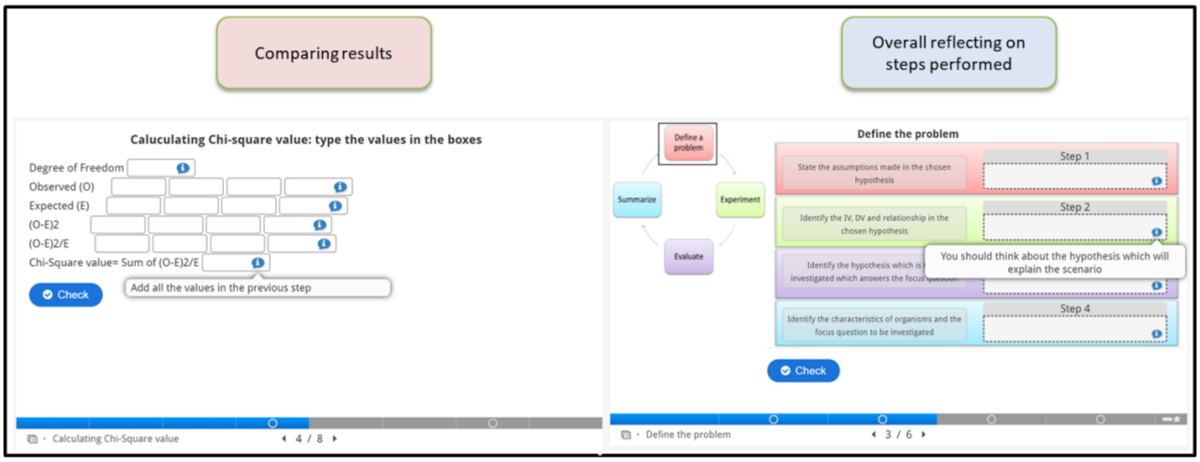

Figure 4. Learning activities in *GI for revising hypothesis*

- *Evaluative Question Prompts*:

The integration of concepts, skills and use of statistics was interspersed with evaluative question prompts to reinforce the understanding of conceptual knowledge (A hypothesis must have ......) or to strengthen the application of conceptual knowledge (Did you think about the following while selecting the hypothesis?) (Xun & Land 2004).

- *Reflective activities:*

Students reflected upon the steps and sub-steps which has to be done while solving a similar scenario and the learning activity required them to arrange them in the correct order.

- *Scaffolds*:

Learners were provided with immediate feedback throughout the learning activities. Along with the feedback, hints were provided to scaffold learners in the problem-solving process. Learners were asked to state their reasoning explicitly in many places, which ensured that they should take an informed decision during the interaction. In addition to that, additional resources related to concepts of genetics and statistics were provided in the form of video, pdf, and solved examples which can be accessed by the learners anytime during the problem-solving process.

These functionalities are incorporated at different steps within the GI. The interactions in the GI required the learners to navigate back and forth with interspersed drag and drop activities in the majority of the learning activities. This approach creates a seamless transition from guided problem solving as done in the traditional classroom to a personalized web-based learning environment to foster and practice problem-solving skill without limiting the solution space which is also aligned to the student's curriculum. The user interface of GI is designed and implemented with Google sites, which is an open-source toolkit. The learning activities of GI have been designed in H5P, which is an open source free HTML5 toolkit to develop interactive contents. H5P supports the creation of interactive learning activities where learners can interact with artifacts available in the environment. The users can access GI through standard web user interfaces through any device. Besides this, group level learning behaviors can be accessed in real time from the Google analytics platform, which is helpful for the teachers to provide real-time feedback.

4. Study Design

4.1 Participants & Context of Study

The participants of this study were sixty-three undergraduate students of Bio-Science at one of the colleges of Mumbai University in India. The participants were randomly assigned into control or experimental group. In this study, we chose the di-hybrid cross following the Mendelian inheritance as the context covered in the learning material. Problem-solving in this topic requires the students to generate, test and revise hypothesis along with connecting concepts related to basics of Mendelian genetics, understand and decide about the appropriate statistical calculation along with inference.

This topic is suitable to be implemented in GI because students are required to identify the underlying reason for biological phenomena, e.g. identifying the inheritance pattern of characters in *Drosophila*. In this topic, there could be multiple underlying reasons like incomplete dominance, co-dominance, etc. Associated with the given task, we expect that the students will have an understanding of the concepts of Mendelian genetics. They have learned it as part of their high school curriculum followed by an introductory genetics course in the first semester of their undergraduate degree. However, they were never made or asked to do open-ended problem solving related to the current topic. In the learning environment, students were provided with the additional resources related to concepts of Mendelian genetics.

4.2 Experimental Setting

This study was conducted as a part of a problem-solving workshop for Bio-science learners. It was conducted in a supervised setting using the GI learning environment for capturing data of the learning gains on problem-solving and their perception of usability of GI. The study had five steps, as presented in the figure 5.

Figure 5. Procedure of Study

The first step required the participants to fill the registration form. It mentioned the learning objective of the workshop, the pre-requisites for the workshop, and questions related to the participant's academic details. The pre-test followed it on the day of the workshop. The pre and post-test questions were validated and checked for its reliability within the research team and subject matter experts. It had six tiers of questions (Table 1). Once the participants attempted the first three questions, they were given the second sheet, which had the remaining questions. They were also provided with the additional resource which had the chi-square formula and table of the critical value of the chi-square distribution. On an average participant took 40 minutes to solve the pre-test.

Table 1: *Sample pre and post-test questions*

Q. No.	Targeted Problem-solving & Process Skills	Relevant part of question statement
1	Identify parts of hypothesis	Why do you think that it is a reasonable hypothesis? Which physical quantities or variables you will measure in this hypothesis?
2	Calculate the predicted value	Calculate the number and type of different progenies if total number of progenies after second generation is 320.
3	Justification for predicted value	State the assumptions, if any, that you are making while predicting the result.
4	Statistical comparison	Does your expected result match the observed result?
5	Decision of hypothesis	What will you do to determine if your hypothesis is correct or not based on the results?
6	Process to solve similar problem	Describe the sequence of steps which you will perform while solving a similar scenario with another organism.

The pre-test was followed by interaction with the learning material. This is where the experimental and the control group have a different activity. In the experimental group, participants interacted with GI, in which they do learning activities of selection, testing, and revision of hypothesis. On the other hand, the control group went through the learning material related to basic concepts of genetics, the importance of model organism, hypothesis formation and how to calculate the chi-square test and compare with the critical value. They also went through the worked examples. The main difference in the learning materials of the two groups were the features of evaluative question prompts with customized feedback, reflection activity, and the drag and drop activities. These learning materials for the control group were in the form of video, pdf, and Google slides, which were organized as Google website. These videos were the same as in the experimental group but did not contain the scaffolds and prompt which were present in GI.

After that, participants of both the groups took the post-test, which was similar to the pre-test. The workshop concluded with the last activity of filling the perception survey. It was implemented through the Google form with an aim for understanding participants' perception of usability and usefulness of GI. We took a traditional survey instrument for testing the usability of GI. For usability testing, we used the 10-item System Usability Scale (SUS) (Brooke, 1996) widely used for assessing the usability of a wide variety of learning environments. We asked additional open-ended questions in the survey to capture participant's perception of gross usefulness and usability of the GI. Target statements of these open-ended questions were as follows:

Q1: What features of the GI did you find most useful?

Q2: After interacting with GI, I learned something which I consider to be valuable. GI is valuable for ….

Q3: How do you plan to use the knowledge you obtained from this online workshop in other topics/subject or anywhere else? Please explain briefly.

5. Data Analysis and Results

5.1 The Effect of GI on Students' Learning Performance

We calculated improvements in learning by evaluating their pre and post-test based on adapted scientific ability rubric. The rubric items correspond to the problem-solving skill as given in Table 2. The inter-rater reliability was high (Cohen's Kappa: 0.774, p-value<0.001). We calculated the average mean value and standard deviation of the scores on sub-skills. On average, the final group score is increasing. Furthermore, we did a statistical test to see if the changes were significant. We did a paired-sample t-test, for both the control and experimental groups. The difference between the average of the post-test score minus pre-test score and μ0 is statistically significant (p-value: 0.000) for the experimental group. The observed standardized effect size is large (0.99). We also did an independent sample t-test on normalized gain.

Table 2: *Rubric Item-wise Statistics of the Pre and Post-test Scores for Control and Experimental Groups*

Problem-solving & Process Skills	**Group**	**Pre-Test: Mean (SD)**	**Post-Test: Mean (SD)**	**Normalized gain**	**Paired t-test: Sig. p-value**	**Independent t-test: Sig. p-value**
Identify parts of hypothesis	Control	1.03 (0.78)	0.86 (0.74)	-0.08	0.13	0.26
	Experimental	1.38 (0.6)	1.38 (0.65)	0	1.00	
Calculate the predicted value	Control	0.69 (1.20)	1.10 (1.05)	0.17	0.12	0.09
	Experimental	1.09 (1.00)	1.76 (0.85)	0.35	0.00	
Justification for predicted value	Control	0.34 (0.55)	0.07 (0.26)	-0.10	0.03	0.00
	Experimental	0.44 (0.75)	0.65 (0.81)	0.08	0.11	
Statistical comparison	Control	0.31 (0.47)	1.03 (0.98)	0.26	0.00	0.52
	Experimental	0.97 (0.9)	1.71 (0.94)	0.36	0.00	
Decision of hypothesis	Control	0 (0)	0.52 (0.83)	0.17	0.00	0.79
	Experimental	0.18 (0.63)	0.71 (1.00)	0.18	0.01	
Process to solve similar problem	Control	0.69 (0.71)	0.66 (0.77)	-0.01	0.81	0.00
	Experimental	0.53 (0.66)	1.41 (0.78)	0.35	0.00	
Total	Control	3.07 (2.55)	4.24 (3.27)	0.07	0.05	0.00
	Experimental	4.59 (3.06)	7.62 (3.46)	0.22	0.00	

5.2 *The Perception of Usability and Usefulness of GI*

We performed thematic analysis for analyzing the response to the three open-ended questions about gross usefulness and usability of GI. The result of our analysis is summarized in Table 3. Participants found the interactive video, question prompts for reflection, drag and drop learning activity and understanding of domain as useful features of GI. Analysis of the result of the two questions related to the usefulness of GI reveals that GI helps in learning of the skill of hypothesis testing and revision and learning of genetics concepts. The SUS survey responses were used to calculate the SUS score as per standard method (Brooke, 1996). The SUS score came to 63.35, indicating the product is usable.

Table 3: *Themes and Respective Sample Excerpts*

Q1. What features of the GI did you find most useful?			
S. No.	**Theme**	**Meaning**	**Instance of responses from participants artefacts**
A	Interactive video	The content of the video and interspersed reflective questions	"I liked the videos and the question answer format in between the videos"
B	Question prompts	Multiple choice questions for the purpose of reflections and embedded hints	"...the hints provided to solve the questions…."
C	Drag and drop activity	Drag and drop activity related to the steps of experimental processes.	"….the way it taught each and every detail about the experiment..."

D	Domain of genetics	GI helped in understanding of concepts related to genetics	"the genetic analysis was very useful"
Perception of Usability of GI Q2. After interacting with GI, I learned something which I consider to be valuable. GI is valuable for …. Q3. How do you plan to use the knowledge you obtained from this online workshop in other topic/subject or anywhere else? Please explain briefly			
S. No.	**Theme (Learning of ….)**	**Meaning**	**Instance of responses from participants artefacts**
A	Problem solving and process skills	Identifying the instances and applying the series of steps	"I plan to use it whenever I have problems in solving genetics….like first setting a hypothesis, comparing the expected and observed values and finally concluding the hypothesis"
B	Domain	Understanding and applying the concepts of genetics	"knowing the genetics concepts in more easy and interactive way and applying the learned knowledge"
C	Statistical concepts	Application of statistical concepts in a particular scenario	"solving the mathematical sums online" "can be used in biostatistics"
D	In advance studies	Apply the knowledge learnt in other topics in bio-sciences and in advanced studies	"as I aspire to complete my masters in genetics I found it really helpful and yes it cleared my basics"

6. Discussion and Future Work

Overall the experimental group demonstrated high learning gain in the application of problem-solving skills as compared to the control group. The most likely explanations for this observation would be that the conjectured design features of GI were useful for the learning of problem-solving skills. It is supported by the fact that the participants were able to identify and state the interactive design features as found in the thematic analysis of the feedback questions. Some of the design features which are worth mentioning are interactive video, reflective and evaluative question prompts and the drag and drop activity.

Rubric wise analysis of learning gains reveals that interaction with both the control and experimental learning material resulted in higher effectiveness in teaching the application of procedural steps like calculation of the predicted value and making the statistical comparison. Stated differently, the participants seemed to understand the application of procedural steps. This is not entirely unexpected as they are used to the kind of teaching method in which the teacher, demonstrates the steps and the students mechanically apply those steps in similar problems. In GI, instead of the teacher these participants watched the interactive video explaining steps of Chi-square calculation. In contrast to the learning gain of procedural steps, the learning gain of process skills, e.g. justification for the predicted value and decision for the hypothesis was not significant for both the groups. This result is following the findings reported in the existing literature that learning of skills requires multiple interactions over some time (Kim & Hannafin, 2011). Based on the result, we conjecture that multiple interactions with GI and across contexts will lead to significant learning gain.

High learning gain in the experimental group for learner's response to the last question which was about steps required to solve similar problems revealed that GI helped them to identify and reflect on steps and sub-steps performed for similar contexts. This result is worth discussing as this high learning gain in this question could be attributed to the summarizing activity. In this activity, since participants had to reflect upon overall learning activity and its sub-activities, they were able to abstract the steps of problem-solving. The drag and drop activity in GI provided them the flexibility of sequentially arranging the steps and access the hints as and when required. We conjecture that because of this, they were able to demonstrate the skill explicitly in the answers of the post-test questions. Along with that, thematic analysis of open-ended question responses revealed that GI is valuable for the learning of process skills of hypothesis testing and revision. Besides this, they also perceive that interaction with GI will help in better understanding of genetics and statistical concepts and will help in advance studies. GI was marked as a usable product based on the SUS score. Repeated use of the tool is likely to boost their confidence in interacting with the tool. The web-based learning environments make learning flexible, portable, and attractive (Hashemi, Azizinezhad, Najafi, & Nesari, 2011).

Our next development work includes analysis of the users' feedback to modify or implement additional functionalities in the learning environment. We would also like to validate the conjecture of cognitive process performed by the students while interacting with GI through eye-tracking and identify the pedagogical and interface design changes needed as part of our future work.

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References

Bahar, M., Johnstone, A. H., Hansell, M. H. (1999). Revisiting learning difficulties in biology. Journal of Biological Education, 33(2).

Bransford, J. D., Brown, A. L., & Cocking, R. R. (2000). How people learn (Vol. 11). Washington, DC: National academy press.

Brooke, J. (1996). SUS-A quick and dirty usability scale. Usability evaluation in industry, 189(194), 4-7.

Chen W., Looi C., Xie W., & Wen Y., (2013) Empowering argumentation in the science classroom with a complex CSCL environment. In Proceedings of the 21st International Conference on Computers in Education. Indonesia: Asia-Pacific Society for Computers in Education.

Concord Consortium. (2010). Geniverse (Accessed: 16 May. 2019). Geniverse [Online]. Available: https://geniverse-lab.concord.org

Cooper, S., Hanmer, D., & Cerbin, B. (2006). Problem-solving modules in large introductory biology lectures. The American Biology Teacher, 68(9), 524-530.

Deep, A., Murthy, S., & Bhat, P. J. (2016, December). Geneticus Investigation: An Agent-Based Modeling System for Teaching-Learning Hypothetico-Deductive Reasoning in Mendelian genetics. In 2016 IEEE Eighth International Conference on Technology for Education (T4E) (pp. 164-171).

De Jong, T., Sotiriou, S., & Gillet, D. (2014). Innovations in STEM education: the Go-Lab federation of online labs. Smart Learning Environments, 1(1), 3.

Fernandes, R., & Simon, H. A. (1999). A study of how individuals solve complex and ill-structured problems. Policy Sciences, 32(3), 225-245.

Hashemi, M., Azizinezhad, M., Najafi, V., & Nesari, A. J. (2011). What is mobile learning? Challenges and capabilities. Procedia-Social and Behavioral Sciences, 30, 2477-2481.

Ibáñez Orcajo, T., & Martínez Aznar, M. (2005). Solving problems in genetics II: Conceptual restructuring. International Journal of Science Education, 27(12), 1495-1519.

Jouble (2013). h5p.org (Accessed: 20 May. 2019). H5P [Online]. Available: https://h5p.org/

Karagoz, M., & Çakir, M. (2011). Problem Solving in Genetics: Conceptual and Procedural Difficulties. Educational Sciences: Theory and Practice, 11(3), 1668-1674.

Kim, M. C., & Hannafin, M. J. (2011). Scaffolding problem solving in technology-enhanced learning environments (TELEs): Bridging research and theory with practice. Computers & Education, 56(2), 403-417.

Makransky, G., Bonde, M. T., Wulff, J. S., Wandall, J., Hood, M., Creed, P. A., ... & Nørremølle, A. (2016). Simulation based virtual learning environment in medical genetics counseling: an example of bridging the gap between theory and practice in medical education. BMC medical education, 16(1), 98.

Pedaste, M., Mäeots, M., Siiman, L. A., De Jong, T., Van Riesen, S. A., Kamp, E. T., ... & Tsourlidaki, E. (2015). Phases of inquiry-based learning: Definitions and the inquiry cycle. Educational research review, 14, 47-61.

Quintana, C., Reiser, B. J., Davis, E. A., Krajcik, J., Fretz, E., Duncan, R. G., ... & Soloway, E. (2004). A scaffolding design framework for software to support science inquiry. The journal of the learning sciences, 13(3), 337-386.

Slotta, J. (2002). Designing the web-based inquiry science environment (WISE). Educational technology, 42(5), 15-20.

Thompson, N., & McGill, T. J. (2017). Genetics with Jean: the design, development and evaluation of an affective tutoring system. Educational Technology Research and Development, 65(2), 279-299.

Xun, G. E., & Land, S. M. (2004). A conceptual framework for scaffolding III-structured problem-solving processes using question prompts and peer interactions. Educational technology research and development, 52(2), 5-22.

Yin, C. J., Uosaki, N., Chu, H. C., Hwang, G. J., Hwang, J. J., Hatono, I., & Tabata, Y. (2017, January). Learning behavioral pattern analysis based on students' logs in reading digital books. In Proceedings of the 25th International Conference on Computers in Education (pp. 549-557).