A WEB-BASED INTRODUCTION TO BIOINFORMATICS
Epistemological beliefs in bioinformatics

Gerald Lirk[1], Peter Kulczycki[1] and Jörg Zumbach[2]
[1]*Medical Informatics and Bioinformatics, Univ. Appl. Sci. Upper Austria, Softwarepark 11, 4232 Hagenberg, Austria*
[2]*Department of Science Education and Teaching, University of Salzburg, 5020 Salzburg, Austria*
gerald.lirk@fh-hagenberg.ac.at, peter.kulczycki@fh-hagenberg.ac.at, joerg.zumbach@sbg.ac.at

Keywords: Epistemological beliefs, Knowledge, OpenLab Projects, Learning Bioinformatic tools

Abstract: An OpenLab learning course, taking place in both class room and wet and computer lab, was used to explore the image on bioinformatics reflected by undergraduates and students. Three main aspects were investigated. First, what is their opinion about the bioinformatics working environment? Second, how can biological, mathematical and scientific knowledge increase and third, do epistemological beliefs change during attendance of a specific course? A total of 735 persons were surveyed with two different, newly designed, questionnaires. The participants consider bioinformatics more biological than graduated scientists. The increase of knowledge is significantly higher when doing additional data analysis and computer work than working only in the wet lab. We found also a significant change in the epistemological beliefs. Therefore, we recommend a data analysing lecture and online-support in an OpenLab-course. Respectively, we recommend an interdisciplinary introduction to bioinformatics.

1 INTRODUCTION

Bioinformatics as an interdisciplinary science is best suitable for an introduction to both students and undergraduates to show them the best approach to science. To verify this, we established a course module for starters in biology and bioinformatics, including an e-learning platform and practical works in wet and computer labs. The participants were asked for their opinion on bioinformatics (similar to Barton, 2008), science and the nature of knowledge and knowing. We compared their view at the beginning and at the end of the course with the help of standardised questionnaires.

1.1 Epistemological Beliefs

The bases of scientific work are appropriate techniques in the laboratory and at the computer. First, an experiment must be planned and realized, an object has to be described, measured or modified. The collected data must be checked against a pre-formulated hypothesis. This evaluation is often associated with mathematical work on the computer. However, even in natural sciences, it is not always possible to make unambiguous statements. Due to the subjective understanding of science (= epistemological belief), every person has their own view of science and its limitations. There is no doubt that with increasing experience in science, this understanding will change (Urhahne, 2004).

1.1.1 History

Epistemological beliefs, or beliefs about the nature of knowledge and knowing, have been subject to research for 50 years and are still a target of high research interest (Conley 2004, Billett 2009, Porsch 2010).

The study of epistemological beliefs began with the work of William G. Perry (Perry, 1968/1999), who in the late 1950s interviewed Harvard college students using open interviews about their experiences and insights during their college years. At the beginning of their college time students believed that knowledge was passed from authorities to students as simple, immutable facts. At the end of their degree, however, they concluded that knowledge was complex and changeable, and based on rationale and empirical studies (Schommer-Aikins, 2004). Perry developed a nine-step scheme of intellectual and ethical development, in which he describes the mental changes of the subjects.

Starting with these initial studies further research analysed the epistemological beliefs using mostly longitudinal studies and proprietary models. King and Kitchener (1992, 1994, 2002, 2004) developed a seven-step development model based on interviews (i.e., the Reflective Judgement Model). This model represents epistemological beliefs - similar to Perry (19??) - in one dimension. According to King and Kitchener (1992; Urhahne, 2004) most senior level college students reach most commonly level four, the "quasi-reflective stage". Here knowledge is vague and ambiguous.

With the works of Schommer (1990, 1992, 1995, 1998) the access to explore epistemological beliefs changed: From this point of view they are not seen as a single, continuously changing construct, but rather as a complex system of independent ideas. In her works she analyzed these components with quantitative questionnaire. Four layers were found (Schommer-Aikins, 2003):

- Stability of Knowledge: never-changing vs continually evolving.
- Structure of Knowledge: scattered pieces vs strongly interacting concepts.
- Speed of knowledge acquisition: very fast / never vs step by step.
- Ability to learn: from birth set vs lifetime improvement.

A fifth dimension, the "source of knowledge" (passed by authorities vs purchased by empirical evidence and logical thinking) was suggested by other researchers in questionnaire studies (Jehng, 1993; Schraw, 2002).

1.1.2 Determinants

Various factors influence the development of epistemological beliefs:

Culture: In most models one expects an interaction between the learners and their environment. Therefore, it is obvious that culture has serious impact on people`s behaviour. The factor structure of Schommer (1990) could not be replicated in other cultures. This suggests that this model (and maybe other models too) is not transferable to other cultures and that there are appropriate cultural influences on the development of epistemological beliefs (Chan, 2002; Tasaki, 2001).

Gender: Gender differences were already predicted and studied in the 1980s (Belenky, 1986; Baxter Magolda, 1992). Nevertheless, these results are not unambiguous. Bendixen (1998), Chan (2002), Buehl (2002) and Conley (2004) found no differences, whereas Wood (2002), Schommer-Aikins (2002) and Hofer (2000) found gender-specific variations in each dimension. For instance, the latter describes, that women at the beginning of college consider knowledge as less secure and rely less on authority than their male colleagues.

Age and education: The studies cited above were conducted among older adolescents and young adults, presumably because the researchers worked in higher education. The studies with younger participants reveal the following results: pre-school children show a pre-dualistic stage, in which only the personal view is accepted as true and equal coexistence is not accepted (Burr, 2002). Among primary school children different dimensions and stages of development of the epistemological belief of different models could be shown (Conley, 2004; Elder, 2002). Obviously, education shows a greater influence on the formation of epistemological beliefs than age (Conley, 2004; Schommer, 1998).

Methods of Measurement: To determine epistemological beliefs, several methods have been developed. Especially at the beginning of this research, qualitative interviews were conducted (Hofer, 2004; King, 1994; Perry 1970/1999). These approaches resulted in one-dimensional models of the development of epistemological beliefs; later multifactorial theories were developed on the basis of questionnaire surveys (Belenky, 1986; ; Hofer, 2002; Jehng, 1993; Schommer, 1990). Wood (2002) showed that the questionnaires had specific problems with reliability and reproducibility. On several occasions difficulties with the questionnaire by Schommer were described (Clarebout, 2001; Qian, 1995).

1.2 Open Labs

OpenLabs are widely used for extracurricular education of students, especially in physics and biology (Anon., 2011). There, classes are invited to special courses, doing experiments on their own. Engeln (2004) and Euler (2005) describe the aims of such lab projects for students:

- Promoting interest in and openness to technology and science.
- Convey scientific content, working methods, and views.
- Convey the importance of science and technology to society.
- Breakdown threshold of fears and reservations about science and technology.
- Secure the next generation of technical and scientific courses and professions.

Since 2008 the OpenLab in Hagenberg, Austria (lab-xperience, see www.lirk.at/lab, in German) has been offering schools the opportunity to both conduct molecular biology experiments and to evaluate the data online, using partly specially developed computer programs (Fig. 1). This module is also used for first year undergrads in bioinformatics. Other OpenLabs in German-speaking countries have either wet lab or information science courses.

The aim of this study is to determine a possible change of epistemological beliefs and the growth of knowledge among students in the course of the project (preparation, laboratory work, data analysis).

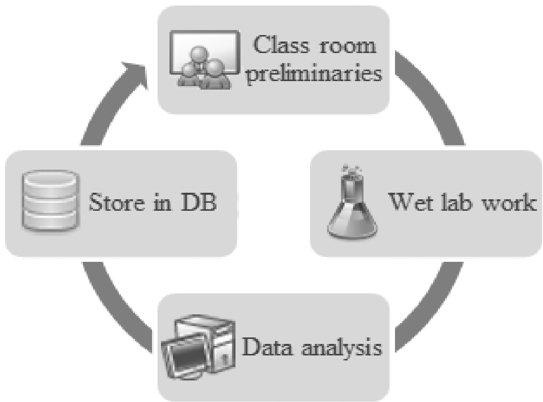

Figure 1: Sequence of an OpenLab-"project": the lecturer introduces the subject to the class. The students work independently with the provided online information (top). After that they collect data in the wet lab (right). These data are further evaluated using the computer (bottom) and stored for further investigations in a database (left). In this way we obtain a larger amount of data. Following classes can anonymously access these data and carry out more accurate statistical analysis.

2. METHODS

2.1 Infrastructure

The e-learning-platform is based on PHP 5 with a mysql-database, accessible via www.lirk.at/lab with a personal password for each lecturer and participant. First the lecturer selects the background of the students or undergraduates, e.g., lab techniques, statistics, algorithms or genetic testing. Depending on this selection, a specific learning task is assigned to the students.

The wet lab has 15 equally equipped workplaces. Larger classes were split during the period of DNA isolation and PCR.

2.2 Questionnaires

Two questionnaires were conducted during our study: First, we asked students about their view on bioinformatics in a Likert-scaled (1-5) questionnaire with 44 items about job profile, the required expertise of a scientist in bio-information sciences, their scope of tasks and duties and their working place. These data were compared with the answers given by graduated students.

Based on their experience, we divided the surveyed in four groups:

- External: 87 students who have never heard anything about bio-information sciences before or had a first visit to our OpenLab.
- Pre: 65 students were interviewed before the start of the wet lab section of an OpenLab course.
- Post: 77 students were asked after the wet lab course.
- Standard (=Graduates): 29 graduates were asked as a standard group. They had completed at least a five-year degree in bio-information sciences. They worked on bio-information science projects already in the second year of their studies and did both their Bachelor`s and Master`s degrees with companies or institutes for about two years. Some of them were asked about their view on bio-information sciences some years after completion of their degree and extensive work experience in that field.

On the other hand, the epistemological beliefs and the growth of knowledge in bioinformatics were explored. Unfortunately, existing questionnaires (e.g. from Schommer, 1990) lack of poor reliability and inconsistency in factors (Wood, 2002). Therefore, in a first step, a separate questionnaire was developed (also Likert-scaled), measuring the factors of scientific sources, development, methodology and review. In parallel, in the same questionnaire, the increase of knowledge was determined with 22 items. This questionnaire was given twice: before the wet lab course started (i.e., pre-test) and after the lab work or after data analysis respectively (i.e., post-test). The test consisted of questions and single choice answers about DNA, molecular biology methods (PCR), scientific working and statistics.

Over a period of two years, about 30 classes were surveyed in four phases. The students and first year undergrads did the following (Table 1):

- Phase I: 161 conducted the wet lab experiments including an oral presentation, but without online support (flash-animations, computer programs and bioinformatics analysing tools).
- Phase II: 147 conducted the wet lab experiments and additional presentation of data analysis and bioinformatics tools.
- Phase III: The online platform was presented to 127, but hardly used. Therefore, this phase is nearly the same as phase II.
- Phase IV: 42 participants performed the entire project including the use of the online platform.

Table 1: The participants finished different parts of the course module, depending on the phase. The numbers of "x" show the intensity with which the students and first-year undergraduates worked.

Finished work	Phase			
	I	II	III	IV
Online Preparation			x	xx
Wet Lab	xxx	xxx	xxx	xxx
Presentation biology	xxx	xxx	xxx	xxx
Presentation bioinformatics		xx	xx	xxx
Data analysis		x	x	xxx

All questionnaires were paper-based. The answers were transferred to MS Excel and exported to SPSS. The statistical analysis was done using SPSS 17.

2.3 Class Project

Most frequently, both students and undergrads chose a module called "CSI Hagenberg". There an ALU-Sequence (Alfred-DB UID SI000152I, Rajeevan, 2011) in the DNA of each participant was analysed (Batzer, 2002). In phase IV of our study the following steps had to be taken:

2.2.1 Online Preparation

Before coming to the wet lab, the participants had to take some preliminaries on the computer:

- Reading operating instructions.
- Watch some flash animations of working skills (pipetting, preparing a dilution series, procedure of PCR, etc).
- Solving some tasks (calculating centrifuge acceleration, finding primer sequences, Calculation annealing temp cf. Robertson, 2008).
- Learning about the rules of Mendalian inheritance and human pedigrees with computer programs and games.

2.2.2 Working in the wet lab

The course lasted app. 5 hours. In this time particpants had to isolate DNA and a PCR had to be completed. PCR was carried out with a VWR thermal cycler for 35 cycles, followed by an Agarose gel electrophoreses. The result was a picture of the gel with a DNA-marker and 1-2 fragments for each participant.

2.2.3 Presentation biology

While PCR was running, the Mendelian rules and PCR technique were repeated and the biology of ALU- and VNTR sequences were described.

2.2.4 Presentation of bioinformatics

The biological explanations were supported by different bioinformatic databases and tools and the algorithms behind them were briefly explained:

- Genebank for searching the special ALU sequence.
- DotPlot for comparing the sequence with/without ALU and showing the poly-A-part inside ALU.
- Ensembl-Blast and lAlign for seeking the primer sequences in the human genome.
- Sometimes clustalW for creating a phylogenetic tree of ALU-Sequences.

2.2.5 Data analysis

After producing genetic data in the wet lab and explaining both biology and the tools, the participants worked on their own data. They should:

- Calculate the size of their DNA fragments on the gel-image with the help of the DNA marker and a regression analysis with MS Excel.
- Making a descriptive statistics about the genetic data of the class.
- Compare these data with the data of all students and undergrads taking the course so far with inductive statistics.
- Calculate the Hardy-Weinberg equilibrium.
- Consider and calculate sensitivity and specificity of medical tests.
- Discuss the need for positive and negative controls, referring to newspaper articles about

the “phantom of Heilbronn”, a German criminal case, where contaminated sample sticks were used.

3. RESULTS

3.1 Opinion about bioinformatics

258 students were asked about their view on bioinformatics. The average age was 17.2 years(SD = 1.5 years). 56% were female. We used the answers given by 29 graduates from our university as a standard to compare with the interviewed students in this survey (see above).

The overall picture that students have about bioinformatics is questioned in one point. The result is shown in Figure 2.. Students` view on bioinformatics differs significantly from the one of graduates. The latter see themselves as computer scientists, data analysers and statisticians (specified in an open question). Students consider bioinformaticians more or less as specialists both in computer science and in biology. The differences between the non-standard groups are not significant (p>0.1).

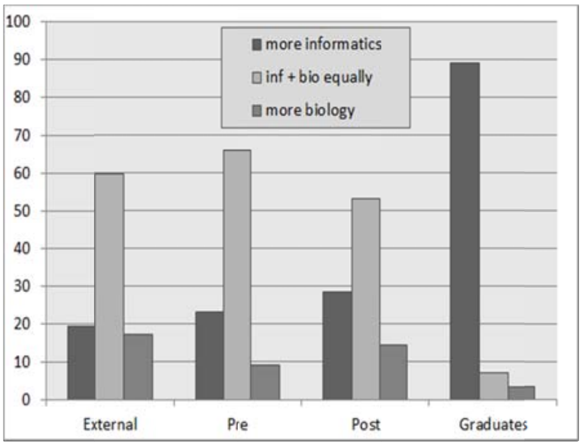

Figure 2: The chart shows (in percentage) what students think about the work of a bioinformatician. Answers in percentage to the question: “Do you consider a bioinformatician more to be a computer scientist or a biologist?”

How sure are the respondents about their view on bioinformation sciences? The confidence here differs between the groups (see Figure 3). There is no difference between the external and the pre-group (p=0.7), but the believes changes from pre to post (p<0.001). The intervention between pre and post was a 5h wet lab course including a presentation without data analysis. The difference to the graduates (standard-group) is highly significant (p<0.001), as they are more confident with the working field of computational biologists.

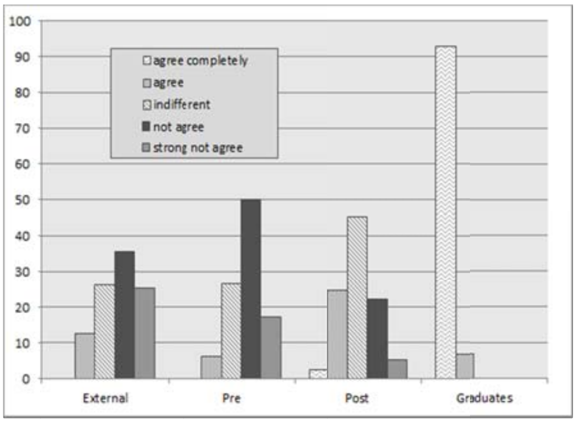

Figure 3: The self-image differs considerably between the groups. Presented are the answers in percentage to the question: “I have a clear understanding of the tasks of a bioinformatician.”

In six out of 44 items we found significant differences between the pre and post group, so the image changed during the intervention. Such differences could be shown in 30 items between the post- and the standard group. The items of the poll can be classified as follows: work, workplace, general competencies and special competencies. Table 2 shows one question per class.

Table 2: The scales of the answers were from “agree fully” (++) to “reject fully” (--). The four different groups are always listed in four lines: three groups of students and, as a standard, graduates. The values are expressed as percentage. The difference to 100 result from missing values. The p-value next to the statement is calculated with a t-test, comparing the standard and the post-group.

	++	+	o	-	--
A bioinformatician must think analytically (p=0.076)					
Extern	43	43	11	2	0
Pre	46	45	9	0	0
Post	51	41	8	3	0
Standard	79	17	0	0	3
A bioinformatician develops special computer programs (p=0.003)					
Extern	20	28	26	15	11
Pre	22	28	17	17	17
Post	45	26	9	7	13
Standard	72	21	7	0	0
A bioinformatician deals with clinical data (p<0.001)					

Extern	6	15	22	21	36
Pre	0	11	23	25	42
Post	9	5	21	21	37
Standard	10	41	34	7	7
A Bioinformatician deals with statistics (p<0.001)					
Extern	16	40	31	9	4
Pre	17	34	35	11	3
Post	26	40	25	5	5
Standard	69	31	0	0	0
Bioinformaticians work in research institutions (p=0.041)					
Extern	40	47	12	2	0
Pre	60	34	6	0	0
Post	61	32	7	1	0
Standard	79	21	0	0	0

3.2 OpenLab course

3.2.1 Epistemological belief

In total, 477 persons were examined. The average age was 17.8 years (SD = 1.6). More than 90% were in their last year of high school. 56.3% of the interviewees were female.

Because of the low values in reliability of the questionnaire provides by Schommer (1990; cf. Clarebout, 2001; Qian, 1995, a new questionnaire was constructed based on questions from different other instruments. The result of the factor analysis is shown in table 3. Four factors with a Cronbach's Alpha between 0.36 and 0.76 were found (Cronbach, 1951).

Table 3: Factors with Cronbach Alpha of the newly designed questionnaire. Factors such as sources, development and review showing different reliability scores are numbered 1-4.

Factor		Cronbach Alpha
1	Scientific Sources	0.76
2	Scientific Development	0.65
3	Scientific Methodology	0.36
4	Scientific Review	0.64

This newly designed questionnaire was administered to students and undergraduatess in four different phases twice: the first time before, the second time after the course. The difference of the measured factors between these two tests was calculated and is shown in figure 4.

Figure 4: The comparison of the four questionnaire factors shows the change of epistemological believes in phase IV. The Factor 1-4 of phases I-IV are plot against the difference between pre- and post-test. Factor 1 is raising which shows that after the intervention participants 'confidence in scientific sources' is about one grade (0.83) lower than before. Factor 2, 3 and 4 are lower. As a result, the interviewees believe more strongly in the permanent development of science (-0.31), in the importance of experiments in science (-0.56) and that experiments have to be repeated to achieve a reliable conclusion (-0.39).

The measured differences are highly significant, as table 4 shows.

Table 4: p-values of ANOVA analysis of the four factors between the different phases in the post-test (at least at the end of wet lab experiment). Significant values (p<0.05) are marked with *.

Factor	Phases	II	III	IV
1	I	0.100	0.258	0.000*
	II		0.924	0.000*
	III			0.000*
2	I	0.846	0.539	0.338
	II		0.955	0.082
	III			0.026*
3	I	0.396	0.911	0.022*
	II		0.701	0.000*
	III			0.002*
4	I	0.616	0.999	0.023*
	II		0.585	0.001*
	III			0.008*

3.2.1 Increase in knowledge

The second questionnaire was also administered to assess knowledge acquisition. The questions referred to different topics which were discussed during the course, ranging from biological questions to scientific working and mathematics. Starting off with simple questions reflecting common knowledge of these fields, the questions got more and more challenging. As shown in Figure 5 the increase of knowledge is greatest in phase IV: with an average of 9 (41%) more correct answers (from an overall of 22 questions).

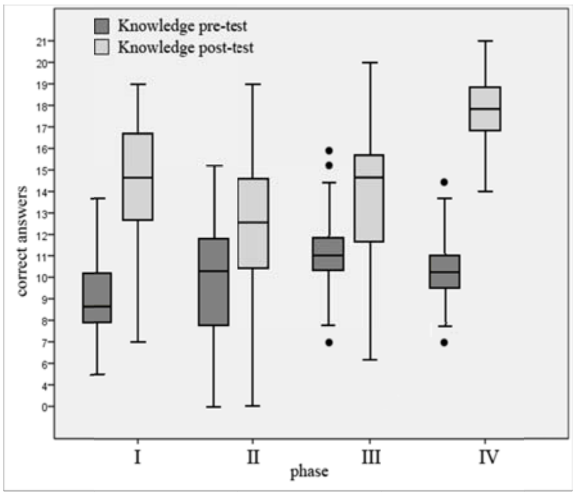

Figure 5: The box and whiskers-plots show the increase of knowledge between the pre-test (dark) and post-test (light) in phases I-IV. The ordinate shows the number of correct answers. The maximum was 22. The increase of knowledge is greatest in phase IV, which includes additional online tools and later data analysis.

Significant differences were found especially in the pre-test in phase III, in the post-test in phase IV (table 5). There is a constant increase of knowledge in the pre-test starting with phase I. One explanation might be that the same teachers heard the topics already during their first visit (phase I) and might have prepared the class (with different students) for the next visit. The knowledge in the post-test is slightly decreasing. Obviously, the presentation of data analysis and bioinformatics tools in such a project alone does not make sense. Significantly better results can be produced by an additional analysis unit at the computer after the wet lab visit. Phase IV shows considerable differences to phase I-III.

Table 5: p-values of an ANOVA. The differences of knowledge change between the phases are presented below. Highly significant is the increase in phase IV.

		II	III	IV
pre-test	I	0.539	0.000	0.076
	II		0.000	0.448
	III			0.387
post-test	I	0.005	0.682	0.000
	II		0.079	0.000
	III			0.000

4 CONCLUSIONS

Online introduction to bioinformatics like the one illustrated here - including a wet lab and a computational part-have several consequences. It was shown that the view students have on bioinformatics already changes during a single wet lab course in a bioinformatics institute. Students lacking contact to bioinformatics tend not to be sure what a computational biologist does for a living.

After visiting the OpenLab they often change their mind just slightly, but results indicate that they are more confident about their believes in what this field of science is about and how it works. Their picture of bioinformatics tends to be similar to the standard (graduates) group, but is less computer science-oriented. This might be explained by the fact that the intervention for this questionnaire here almost only took place in the wet lab. Nonetheless, it could be shown that students consider computer skills (development of algorithms, databases, etc.) for a computational biologist to be significantly more important than before, despite the fact that they did not do any analysis. Mentioning bioinformatics and answering questions about this field is obviously enough.

Another consequence of a bioinformatics OpenLab project is the increase of knowledge. Students could already fall back on more or less general knowledge of biology before the practical course started, e.g., structure of DNA and main principles of PCR. Striking improvement could be achieved in working (e.g. lab security), special PCR knowledge (construction of primers) and important scientific principles (use of markers, blanks and standard) though. Minor changes were observed in the use of positive and negative controls and statistics. The time for learning these scientific and mathematical skills might have been too short. Especially in phase IV, however, there is a significantly higher level of knowledge. That means that working with bioinformatics tools and statistical analysis of data result in a deeper learning and, thus, increased knowledge acquisition. Thus, it seems to be not enough to just show the results of a data analysis and bioinformatics tools. It is rather necessary to spend some time actively working with these data.

The third consequence is the change of the epistemological believes. Only extensive examination of the data of an experiment can change this belief in science. Significant changes could only be seen in phase IV.

Therefore, we strongly recommend a following (computer based) data analysis conducted by students for OpenLabs. This results not only in higher domain knowledge, but also in a better understanding of science and therefore in a more accurate development of higher order epistemological believes. By providing such an approach as mentioned here, students can develop a deeper insight into this discipline resulting in a great step towards a deeper understanding of science.

The limitation of the study is that only three small classes have been carried out so far in phase IV (a longer project time with online support). In future research, this number will be increased.

REFERENCES

Anon., 2011. *LernortLabor.* St.Ingbert: Hempelmann, R., Available from: www.lernort-labor.de [Accessed Date: 2011-11-06]

Barton M., 2008. Manchester. Available from: http://openwetware.org/wiki/Biogang:Projects/Bioinformatics_Career_Survey_2008 [Accessed Date:2011-11-06]

Batzer M.A., Deininger P.L., 2002. *ALU repeats and human genomic diversity*. Nature Review Genetics, 3(5):370-9.

Baxter Magolda, M. B., 1992. *Knowing and reasoning in college: Gender related patterns in students' intellectual development.* San Francisco: Jossey -Bass.

Belenky, M.F., Clinchy, B.M., Goldberg, N.R. & Tarule, J.M., 1986. *Women's ways of knowing: The development of self, voice and mind.* New York: Basic Books.

Bendixen, L.D., Schraw, G., Dunkle, M.E., 1998. *Epistemic beliefs and moral reasoning.* Journal of Psychology, 132(2), 187-200.

Billett, S.,2009. *Personal epistemologies, work and learning*. Educational Research Review 4, 210–219

Buehl, M. M., Alexander, P. A., Murphy, P. K., 2002. *Beliefs about schooled knowledge: domain specific or domain general?* Contemporary Educational Psychology, 27, 415-449.

Burr, J. E. & Hofer, B. K., 2002. *Personal epistemology and theory of mind: deciphering young children's belief about knowledge and knowing.* New Ideas in Psychology, 20, 199-224.

Chan, K. K. & Elliott, R. G. (2002). *Exploratory study of Hong Kong teacher education student's epistemological beliefs: Cultural perspectives and implications on belief research.* Contemporary Educational Psychology, 27, 392-414.

Clarebout, G., Elen, J., Luyten, L., Bamps, H., 2001. *Assessing epistemological beliefs: Schommer's questionnaire revisited.* Educational Research and Evaluation, 7, 53-77.

Conley, A.M., Pintrich P.R., Vekiri, I., Harrison D., 2004. *Changes in epistemological beliefs in elementary science students.* Contemporary Educational Psychology 29 (2004) 186–204.

Cronbach, L., 1951. *Coefficient alpha and the internal structure of tests*, Psychometrika, 16, 3, 297-334.

Elder, A., 2002. *Characterizing fifth grade students' epistemological beliefs in science.* In: Hofer, B. & Pintrich, P. (Hrsg.): Personal Epistemology: The Psychology of Beliefs about Knowledge and Knowing. Mahwah. 347 - 363.

Engeln, K. & Euler, M., 2004. *Forschen statt Pauken. Aktives Lernen im Schülerlabor.* Physik Journal, 3(11), 45-48.

Euler, M., 2005. *Schülerinnen und Schüler als Forscher: Informelles Lernen im Schülerlabor.* Naturwissenschaft im Unterricht - Physik, 16(90), 4-12.

Hofer, B. K., 2000. *Dimensionality and disciplinarity differences in personal epistemology.* Contemporary Educational Psychology, 25, 378-405.

Hofer, B. K., 2004. *Exploring the dimensions of personal epistemology in differing classroom contexts: Student interpretations during the first year of college.* Contemporary Educational Psychology 29, 129-163.

Jehng, JC. J., Johnson, S. D., Anderson, R. C., 1993. *Schooling and students' epistemological beliefs about learning.* Contemporary Educational Psychology 18, 23-35.

King, P.M., 1992. *Special issue on Reflective Judgment.* Journal of Liberal Education, 78, Whole number 1

King, P.M. & Kitchener K.S., 1994. *Developing reflective judgement.* San Francisco, CA: Jossey-Bass.

King, P. M. & Kitchener, K. S., 2002. *The reflective judgment model: Twenty years of research on epistemic cognition.* In B. K. Hofer & P. R. Pintrich (Eds.), Personal epistemology: The psychology of beliefs about knowledge and knowing. Mahwah, NJ: Lawrence Erlbaum, 37-61.

King, P.M. & Kitchener K.S., 2004. *Reflective Judgement: Theory and research on the development of epistemic assumptions through adulthood.* Educational Psychologist 39, 5-18.

Perry, W. G., 1970. *Forms of intellectual and ethical development in the college years. A Scheme.* New York: Holt, Rinehart and Winston.

Perry, W.G., 1999. *Forms of ethical and intel lictual development in the college years. A scheme.* San Francisco, CA: Jossey-Bass (Original published 1968).

Porsch, T., Bromme, R., 2010. *Which science disciplines are pertinent? -Impact of epistemological beliefs on students' choices.* In K. Gomez, L. Lyons, & J. Radinsky (Eds.), Learning in the Disciplines: Proceedings of the 9th International Conference of the Learning Sciences (ICLS 2010), Vol.1 (pp. 636-642). International Society of the Learning Sciences: Chicago

Rajeevan H., 2011. Yale. Available from: Alfred.med.yale.edu [Accessed Date: 2011-11-06]

Robertson A.L., Phillips A.R., 2008. *Integrating PCR Theory and Bioinformatics into a Research-oriented Primer Design Exercise*. CBE Life Sci Educ.; 7(1): 89–95

Qian, G. & Alvermann, D., 1995. *Role of epistemological beliefs and learned helplessness in secondary school students' learning science concepts from text.* Journal of Educational Psychology 87, 282-292.

Schommer, M., 1990. *Effects of beliefs about the nature of knowledge on comprehension.* Journal of Educational Psychology 82, 498-504.

Schommer, M., Crouse, A. & Rhodes, N. , 1992. *Epistemological beliefs and mathematical text comprehension: Believing it is simple does not make it so.* Journal of Educational Psychology, 84, 435-443.

Schommer, M. & Walker, K. , 1995. *Are epistemological beliefs similar across domains?* Journal of Educational Psychology, 87, 424-432.

Schommer, M. , 1998. *The influence of age and education on epistemological beliefs.* British Journal of Educational Psychology 68, 551-562.

Schommer-Aikins, M., Hutter, R. (2002). *Epistemological beliefs and thinking about everyday controversial issues.* The Journal of Psychology, 136(1), 5-20.

Schommer-Aikins, M. , 2004. *Explaining the epistemological belief system: Introducing the embedded systemic model and coordinated research approach.* Educational Psychologist 39, 19-29.

Schraw, G., Bendixen, L. D., Dunkle, M. E. , 2002. *Development and validation of the epistemic belief inventory (EBI).* In B. K. Hofer & P. R. Pintrich (Eds.), Personal epistemology. The psychology of beliefs about knowledge and knowing. Mahwah, New Jersey: Lawrence Erlbaum, 261-275.

Tasaki, K., 2001. *Culture and epistemology: An investigation of different patterns in epistemological beliefs across cultures.* Dissertation. University of Hawaii.

Urhahne, D., Hopf, M., 2004. *Epistemologische Überzeugungen in den Naturwissenschaften und ihre Zusammenhänge mit Motivation, Selbstkonzept und Lernstrategien.* Zeitschrift für Didaktik der Naturwissenschaften 10, 71-87

Wood, P., Kardash, C.A.M., 2002. *Critical elements in the design and analysis of studies of epistemology.* In B.K. Hofer & P. R. Pintrich, *Personal epistemology. The psychology of beliefs about knowledge and knowing* (S.231-260). Mahwah, New Jersey: Lawrence Erlbaum.