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Investigation into the Personal Epistemology of Computer Science Students

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ABSTRACT
In this paper, we investigate the personal epistemology of computing students, that is, their conceptions of knowledge and learning. We review some models of personal epistemological development and describe one of the questionnaire tools that have been used to assess the epistemological beliefs of students studying in other disciplines.

We describe an experiment that uses one of these tools, together with exploratory factor analysis, to determine the dimensions of epistemological beliefs of a cohort of computing students and compare the results with that reported in other contexts. The results, while not reproducing the details of previous work, do seem to suggest that there are indeed multiple dimensions to personal epistemology, and that these can be identified, to a large extent, with those recognised by other researchers. Finally, we make some observations about the importance of personal epistemology for learning in Computer Science and outline further work in this area.

Categories and Subject Descriptors
K.3.2 [**Computers and Education**]: Computer and Information Science Education - *computer science education, information systems education*.

General Terms
Human Factors.

Keywords
personal epistemology, epistemological beliefs, pedagogy, learning, factor analysis.

1. INTRODUCTION
The investigation of the cognitive and metacognitive strategies employed by students in higher education is now well established as a prominent topic of research, both generally within the field of Educational Psychology, and also as an area of study in discipline-specific contexts such as Computer Science Education. However the study of personal epistemology [15], i.e. the way in which students perceive what constitutes knowledge, its boundaries, how it is justified, and how this is related to learning, has not traditionally been a topic of research within the computer science community.

While the subject of epistemology, seen as a fundamental branch of philosophy, has a very long history, the study of epistemological beliefs is more recent. Personal epistemology, which can be considered to be "the subjective counterpart of philosophical epistemology" investigates how the philosophical constructs affect the individual at a psychological level [16]. It may be considered to have originated in the developmental psychology of Piaget [26], while its application to tertiary education began in the mid-1960s with the work of Perry [24].

Interest in personal epistemology from educators in a variety of subjects, ranging from science and engineering [12] to music theory [23], has increased in recent years and there now appears to be a significant and growing body of research that suggests that the topic has important implications for teaching within a discipline. For example, there is evidence that epistemological considerations play an important role in the processes by which students become self-regulated learners, that more "sophisticated" epistemological beliefs are often correlated with higher-order learning outcomes [5], and that epistemological factors play an important role in the solution of ill-structured problems [3,17].

There have been some studies that attempt to apply this work to the subject of computing. Barnard et al [2], for example, have examined the relationship between epistemological beliefs and self-regulated learning in an on-line course. However, the focus in this work appears to be on investigating the use of information technology as a medium rather than addressing issues that are specific to the discipline itself. Tolhurst [34,35] applied epistemological considerations to try to enhance learning in the development of an undergraduate Information Systems course. While this is an important contribution and the results have interesting implications for curricular design, it does not seek to use an epistemological perspective to address issues associated with the subject itself, such as the way in which programming exercises change from convergent to divergent problems or students engaged in software development projects very quickly need to deal with ill-structured problems.

We begin this paper by presenting some reasons why we consider the subject of personal epistemology to be important, both in a general sense and specifically for the discipline of computer science. We then give an overview of some of the relevant background research in the field and describe the developmental model that underlies the methodological tool we used to try to

gain insight into personal epistemology of students, namely Schommer's "Epistemological Beliefs Questionnaire" [32]. This was used as the main investigative tool in an initial study, the results of which are examined. Finally, we discuss further research directions that would be relevant to Computer Science Education.

2. MOTIVATION

This paper attempts an exploratory investigation into the personal epistemology of computing students, which is preliminary to further work in this area [22]. While this subject, which lies at the intersection of philosophy, psychology and pedagogy, is of considerable interest from a theoretical point of view, we believe that a close analysis of the concepts surrounding personal epistemology will show that it is also important to teachers of Computer Science for reasons of good educational praxis.

The primary motivation for this work is evidence that students' epistemological beliefs affect the choices they make about the way in which they learn by influencing a variety of cognitive and metacognitive strategies. These include the choice of learning strategies [6, 28], academic performance [28], cognitive processing [18], openness to conceptual change [27], text comprehension [31], moral reasoning [3], and strategy use [6].

Research suggests that the sophistication of an individual's epistemological beliefs has a strong impact on learning. For example, naive views about the structure [14] and source of knowledge [30] correlate with a tendency to use lower level cognitive processes such as rote-learning and to draw absolute conclusions from contingent information. Naive views about the speed of knowledge acquisition correlate with poor comprehension, while students who view ability to learn as innate, and thus fixed, may be less inclined to develop and use advanced reasoning skills when thinking about ill-structured problems [3]. Conversely, more sophisticated views about an individual's ability to control their own learning are correlated with a greater propensity to persist in education [33]. This suggests that, at the very least, an appreciation of these beliefs by teachers will contribute to a greater understanding of the psychology of learning and so may provide insights into ways to develop more effective pedagogical strategies which can address the needs of specific groups of students.

In addition, it appears that epistemological considerations play an important role in tackling divergent or ill-structured (open-ended) problems. These problems typically do not have a single, correct solution or a specified procedure for completion, and consequently there is a greater need to justify any option chosen over alternatives. Justification is an epistemological process and consequently this suggests that a student's personal epistemology will be an important factor in successful engagement with these types of problem. A number of common teaching practices, such as use of group projects, involve these open-ended problems and we would anticipate that this field of study would contribute to our understanding of effective practice in these areas. In addition, it opens up an interesting avenue of investigation for studying the transition from convergent to divergent problem-solving that frequently occurs in computer science education. Examples of this include the increase in complexity as novice programmers undertake more sophisticated tasks and the transition from "programming" to "software engineering". This work also connects well with earlier efforts to develop a theory for setting up open-ended group project learning environments [9, 10].

Finally, there is the important link between identity and epistemology. Becoming, say, a mathematician, is not just a matter of acquiring competence in a set of mathematical techniques; a crucial element in realising such an identity is the development of an ability to see the world as composed of patterns which are susceptible to mathematical analysis, an understanding often acquired as a form of tacit knowledge through practice and engagement with colleagues. This interpretation of identity in the field of mathematics is not uncontroversial, but there is even less agreement on what identity means for computer science. The question of what it means to be a computer scientist, and how academia inducts students into a community of practice, is a subject of some debate [25] but it is not unreasonable to suggest that part of it involves "learning to think like a computer scientist". It would be interesting to investigate the degree to which current members of the computer science community share a specific conception of knowledge and a common understanding of "ways of knowing" within the subject, and also how this is passed on to new graduates. This, in turn, may have practical implications for issues associated with identity such as curriculum development, academic and industry retention practices, and life-long/wide learning.

There have been a significant number of general studies which try to use some kind of quantitative instrument to investigate personal epistemology in students. Historically, the most common of these has been the Epistemological Beliefs Questionnaire, developed by Marlene Schommer in the early 1990s, and described below. It was therefore decided to use this as the initial data collection tool as both the questionnaire itself and the methodology for data analysis were well-known in the literature, and there were published results for comparison. It should be stressed, however, that it was not the intention to replicate Schommer's results but to see if there were any initial points of contact between her findings and ours.

3. BACKGROUND

3.1 Models of Personal Epistemology

One commonly cited problem associated with the study of personal epistemology is the somewhat bewildering range of terms used in the educational psychology literature to describe the concept itself. Briell et al, in their review [4], describe a dozen frequently-employed terms and almost thirty less-frequent synonyms for the general concept. The more popular terminology includes such descriptors as "personal epistemology", "epistemic beliefs", "reflective judgement" and "ways of knowing" and we use the term personal epistemology as a general description for the field of study.

3.1.1 Perry's Developmental Model

While investigation into the development of an individual's conception of knowledge was a central part of the work of Piaget from the 1930s onwards, research into this area has increased substantially in recent decades. The first study, which specifically addressed the topic in the context of Higher Education, was that of Perry which proposed a general scheme in which epistemological understanding developed through nine stages, grouped together into three phases. In the initial phase, often categorized as absolutist thinking, an individual sees knowledge in polar terms as either right or wrong. Uncertainty is due to lack of analysis of suitable data and can be eliminated by straightforward procedures such as direct observation, appropriate introspective examination or through appeal to some expert authority. In the next phase, this

naïve position shifts into a more relativist stance. There is a significant reaction against the previous dualistic view to the extent that knowledge is now perceived as inherently uncertain and personal to the individual, with recognition of the possibility of multiple views which may depend on context. The main feature of the final phase is an epistemological understanding in which knowledge is constructed by comparing evidence and opinion on different sides of an issue. Knowledge is seen as constructed through a process of reasonable inquiry leading to a well-informed understanding. It also recognizes the contingent nature of personal knowledge, exploring the implications of commitment to individual views. Perry, therefore, presents a model of personal epistemological development which is a linear spectrum ranging from initial "simple" or "naive" views to the more "sophisticated", evaluative stance which he saw as desirable in graduates.

Subsequent work on this type of developmental model has extended the analysis in a number of different directions but, as noted by Hofer and Pintrich [13], a common element in such work is the notion of development by progression from an initial dualistic, objectivist view of knowledge, through to a more subjective, relativistic stance to a final contextual, constructivist perspective of knowledge and its acquisition, and justification. As pointed out by Kuhn [20], this evolutionary structure has practical implications for teaching as epistemological factors determine how students view the components of a theory and its relationship to reality. As an example, consider the development of high-level metacognitive skills such as those associated with critical thinking. At an initial, absolutist level, claims about knowledge are seen as facts which are either correct or incorrect. Critical thinking is therefore perceived to be a straightforward matter of comparing such statements to reality in order to determine their truth or falsity. At the more relativistic level, assertions are considered to be mere opinions, none of which is more compelling than any other, and so any may be selected based on personal preference. At this stage, critical thinking is largely irrelevant as justification is limited to the statement of subjective views. It is only at the final, evaluative stage that assertions are considered to be judgements that can be appraised by argument and reference to evidence. As a consequence, it is primarily at this stage that critical thinking, seen as a method for promoting coherent, logical argument, will be considered useful.

3.1.2 Dimensions of Epistemological Beliefs

This concept of a single, integrated continuum of development was, however, challenged in the work of Schommer (later Schommer-Aikins) in a series of papers [30, 33, 31] which drew on Perry's work but incorporated significant elements from other researchers. These included work by Schoenfeld on the speed of learning [29], beliefs about innate intelligence [11], King and Kitchener's work on reflective judgment [19], and Ryan's work on epistemology and comprehension [28]. While accepting the idea of personal epistemological development, she suggested that it was better conceptualised as a multidimensional belief system, the dimensions of which may be only weakly bound to each other. She retained the idea of a developmental continuum from what she, too, characterised as "naïve" views to more "sophisticated" ones, but applied it to each of the key epistemological beliefs and suggested that development may occur in each at different rates. Epistemological development, in this model, was therefore better described by a trajectory in a multidimensional space rather than by linear progression.

The main instrument used by Schommer for this analysis was her Epistemological Beliefs Questionnaire. This seeks to establish the respondent's level of commitment to a range of statements which reflect a particular epistemological belief. Examples of these include "People who challenge authority are over-confident", "I try my best to combine information across chapters or even across classes", "The most successful people have discovered how to improve their ability to learn", and "Things are simpler than most professors would have you believe".

The questionnaire itself was based on the hypothesis that there were five dimensions through which epistemological development takes place: structure of knowledge, stability of knowledge, source of knowledge, speed of knowledge acquisition, and the learner's control of knowledge acquisition (see Table 1). The first three of these were influenced by Perry's original model. The speed of learning dimension was based on the work of Schoenfield, and the control of knowledge dimension was influenced by Dweck's work on implicit intelligence.

Table 1. Schommer's Dimensions of Personal Epistemology

Dimension	Explanation	Development Continuum	Subset Behaviours (labelled by naïve view)
Structure of Knowledge	How students think about the structure, relationship and organisation of knowledge in a particular domain.	From "*knowledge as isolated, unambiguous bits of information*" to "*knowledge as highly interrelated and integrated set of concepts*"	• Seeks single answers • Avoids integration
Stability of Knowledge	How students think about the contingency of knowledge and the way theories may change over time.	From "*knowledge as unchanging*" to "*knowledge as contingent and subject to continual revision and change*"	• Avoids ambiguity • Knowledge is certain
Source of Knowledge	Where students think domain knowledge can come from.	From "*handed down by authority*" to "*derived from empirical evidence and reasoning*"	• Can't learn how to learn • Success is unrelated to hard work • Ability to learn is innate
Speed of Knowledge Acquisition	How students think about the speed at which they acquire knowledge.	From "*learning as occurring quickly or not at all*" to "*a view of learning as a gradual process*"	• Learning is quick • Learn first time • Concentrated effort is a waste of time
Control of Knowledge Acquisition (Ability to Learn)	How students think about their capacity to control the acquisition of knowledge.	From "*a view that the ability to learn is fixed at birth*" to "*a view that it can be improved over time*"	• Can't learn how to learn • Success is unrelated to hard work • Ability to learn is innate

One difficulty with the study of personal epistemology is that we do not observe these beliefs directly but only infer them from behaviour so these dimensions are, in some sense, hidden. Moreover, several behaviour patterns could result from the same belief. For example, according to Schommer [30], if one considers the dimension for "*structure of knowledge*", the naïve epistemological view is that knowledge is essentially simple and that complexity is due to inadequate analysis rather than any inherent conceptual ambiguity in the information or the interrelationships involved. If a person held this view, there would be a tendency to oversimplify complex information which could manifest itself in two ways: they could tend to focus on one aspect of the problem and neglect others, or else they could artificially reduce the complexity of the relationships between the constituents of the problem by a process of inappropriate compartmentalisation. The epistemological views about structure of knowledge therefore give rise to two subsets of observable behaviour. Using the naïve behaviour as a descriptor, these would be termed "*Seeks single answers*" and "*Avoids integration*" and the questionnaire was developed to elicit responses that could be tied to these behaviours. Using this type of analysis, Schommer identified twelve different observable behaviours for the five hypothesised dimensions of belief (see Table 1). Given a dataset of responses to the questionnaire which measure the observable behaviours, the hypothesis that these behaviours are correlated with specific epistemological beliefs can be tested using the statistical procedure known as exploratory factor analysis, which looks for latent variables (factors) that underlie and give rise to the measured, observable data.

Schommer's conceptualisation of personal epistemology as a belief system has been extremely influential in the educational psychology literature as a model of epistemological development. It provides a methodology for quantitative analysis of epistemological data and can also accommodate instances in which students exhibit sophisticated epistemological beliefs in one dimension but less complex beliefs in another, something which is more problematic in one-dimensional models. There has, however, been criticism of this approach due to reported difficulties associated with replicating the factor structure she described [8]. This leads, among other things, to ambiguity in the number of dimensions, i.e. important beliefs, that characterise an individual's personal epistemology Nevertheless, there are a relatively large number of studies that use the method and we have attempted to follow her methodology in our study.

4. METHOD

4.1 The Participants

Our study involved data collected from a group of twenty-five respondents from a total of thirty students involved in a globally distributed group project [21] undertaken by students from Uppsala University, Sweden, and Rose-Hulman Institute of Technology, USA. The data was collected at the beginning of the academic year at the start of the course unit when both Swedish and American students were in Uppsala. The course unit was taught in English and students participating in it in 2012 were aged between 20 and 38 with the majority of students pursuing a major in computer science or information technology (although some students were studying other technical majors). Most students had studied for at least three years at university. The female:male ratio in the cohort from which the data was drawn was 13%. In addition to the scripts used for the dataset, there was one additional questionnaire that was discarded due to non-completion.

4.2 The Instrument

The main investigative tool for this study was Schommer's Epistemological Beliefs Questionnaire which tries to investigate a range of epistemological commitments by asking respondents to indicate levels of agreement to a series of sixty-three statements on a five-point Likert scale. As described in section 3, these statements are grouped into twelve subsets, which describe different behaviours correlated with different epistemological beliefs and act as observed or measured variables for further statistical analysis. The Likert scale values for each respondent for questions associated with an observed variable describing behaviour, such as "*Seeks single answers*", are then averaged and it is these twelve averages that are used to characterise the behaviour of the respondent. These quantities taken for all the respondents form the dataset on which exploratory factor analysis is performed using MINITAB.

The aim of factor analysis is to reduce the dimensionality of the dataset by looking for latent factors that underlie the structure of the observed variables. For example, if (as suggested by Schommer) the behaviours described by the phrases "*Seeks single answers*" and "*Avoids ambiguity*" are really derived from a single epistemological belief about the structure of knowledge, then there should be a high degree of correlation between the responses to questions that track these behaviours in an individual's questionnaire. What is more, even though different people will have different individual values for the behaviours associated with a single belief, a correlation between the behaviours should be observed across the whole set of respondents. If this is so, (and if we have a sensible mechanism by which the behaviours arise from the beliefs) then this provides evidence for those (unobservable) beliefs.

The latent factors derived from this type of analysis should account for the majority of the variation in the observed variables but the variation explained by a particular factor is related to the size of its eigenvalue in the correlation matrix. The larger the value of the eigenvalue, the more important it is in explaining the overall variation. Eigenvalues of the correlation matrix were extracted using principal component analysis and a set of "factor loadings" for each set was produced. A loading for a particular variable, with regard to a factor, quantifies the variation in the measured variable that is explained by that hidden factor. Loadings take values in the range [-1, 1] where a value close to zero indicates that the factor contributes little to the measured variable, a high negative value indicates a strong correlation to the "sophisticated" end of the correlated behaviour and a high positive, to the "naïve" end. Interpretation of the factors themselves proceeds by rotating the axes in the factor space so that the loadings show high values for a few variables and low values for the remaining ones. A common concept underlying the behaviours associated with the high loadings is then used to describe the factor. Following Schommer's original paper, an orthogonal varimax rotation was used for this.

5. RESULTS: IDENTIFICATION AND INTERPRETATION OF FACTORS

Principal Component Analysis was used to extract the eigenvalues of the correlation matrix for the dataset. Analysis of the eigenvalues of the correlation matrix suggested five factors were present and so factor analysis with five factors was carried out on

the dataset, using MINITAB. A table of loadings for the set was produced. These were then rotated using an orthogonal varimax rotation to try to identify the factors. The ratio of sample size to number of measured variables for the dataset is relatively small, but the communalities are reasonably high (for real data). In her original paper, Schommer used a loading threshold of greater than 0.5 to determine contribution to measured variables but, because of the relatively small sample size, we used a higher value of 0.7. Schommer reported that four of her five factors emerged from the statistical analysis. Our analysis suggested five factors. A comparative analysis done with four factors shows that there was no compelling reason to reduce this to four.

A basic analysis of the five factors gives a fairly good fit with Schommer's five dimensions. The first factor, i.e. the one with the highest eigenvalue, has a large contribution to the variables "*Seeking single answers*" and "*Avoiding ambiguity*", which seem, intuitively, to be linked. Although not in agreement with Schommer's categorisation, it seems reasonable to us that both behaviour descriptors relate to an avoidance of multiple representations of knowledge and so we would categorise both behaviours as indicating some kind of belief related to the "*Structure of knowledge*" dimension. The fifth factor was associated with the single variable "*Thinks knowledge is certain*" and with Schommer's "*Stability of knowledge*" dimension. None of the five factors seem to be related to the "*Source of knowledge*" dimension. The third factor is related to the stance that if one is going to learn something then its should be possible to "*Learn it the first time*" and that "*Concentrated effort is a waste of time*". This again seems intuitively sensible and Schommer categorises both of these variables as referring to the "*Speed of knowledge acquisition*". The fourth factor is strongly associated with the view that one "*Cannot learn how to learn*" and that "*Success is unrelated to hard work*". Schommer categorised both as concerned with "*Control of knowledge acquisition*". The view that "*Ability to learn is innate*" is also associated with this factor, but the loading for this is smaller. The second factor is negatively correlated with the measured variables "*Avoids integration*", "*Depends on authority*" and "*Ability to learn is innate*", i.e. the group would tend to integrate knowledge, not rely on authority and trust their own ability, which we see as being associated with the "*Control of knowledge acquisition*" dimension. We thus have two factors capturing slightly different aspects of this dimension.

6. CONCLUSION AND FURTHER WORK

Our aim in this paper has been to start to address some of the issues around personal epistemology within a discipline-specific context of Computer Science Education and the study should be seen as an initial attempt towards this goal. The main technique used for data analysis here is factor analysis and while this form of investigation can be quite sophisticated, we would want to emphasise the exploratory nature of the process here. We have made a preliminary analysis of a small cohort of students and presented descriptive, quantitative results. The analysis does not reproduce the factor loadings described in Schommer's paper, but her work examined a much more general setting than ours and our main interest here is not to replicate Schommer's findings but to use her work to investigate a multidimensional developmental model in a discipline-specific context. Schommer obtained four of her five hypothesised dimensions through exploratory factor analysis whereas we obtain five factors from this procedure. Nevertheless, of her five dimensions of epistemological belief, we arrive at four factors labelled by "*structure of knowledge*", "*stability of knowledge*", "*speed of knowledge acquisition*" and "*control of knowledge acquisition*". The remaining factor, "*source of knowledge*", does not seem to emerge from the analysis in any recognisable form.

We would stress some of the limitations of this study. It was carried out on a very small sample. A comparative study with a larger cohort has also been done and the results of this will be reported elsewhere [22]. Factor analysis requires a reasonable sample-size to variable-number ratio and this study is at the very lowest limit of this. The group studied was also culturally quite diverse and analysis suggests that the questionnaire appears to be quite sensitive to linguistic and cultural factors. Internal consistency measures for the measured variables were also quite low. Moreover, the discipline-specific nature of the group is not adequately addressed by the questionnaire and it is likely that an instrument which is much more tailored to subject context will be needed to further investigate personal epistemology in our subject area. Additional work to clarify these issues is in progress.

Looking forward, we think it likely that the enquiry into personal epistemology will offer important insights into the differences between the methods of solution for well-structured and ill-structured problems [17]. Recent work by Angeli and Valanides [1] has drawn attention to the importance of epistemological considerations for the solution of ill-structured problems. Well-structured problems are convergent, i.e. have a single correct or best solution, or a correct approach to finding that solution. For these types of problem, the focus for the justification of a (correct) solution is on developing a logical argument to support it. In contrast, the solution of an ill-structured problem, which may not even have an optimal solution, often requires consideration of multiple points of view and the need to evaluate a range of criteria to find one satisfactory solution among a large number of alternatives. It therefore becomes necessary to justify the rationale behind the selection of one particular solution that takes into account supporting arguments, opposing perspectives and competing claims [36].

Two significant conclusions taken from the work of Voss and Post [36] on divergent problems are that "research has consistently shown that performance in solving well-structured problems is independent of performance on ill-structured tasks" and "ill-structured problems engage a different set of epistemological beliefs, and thus a different process for developing justification about the problem at hand". Further consideration of these points may be of great practical importance in computing education where a characteristic feature of a wide range of problems, from software engineering to collaborative group projects, is the divergent, open-ended nature of the solution process. Further work in this area is underway.

7. REFERENCES

[1] Angeli, C. and Valanides, N., 2012. Epistemological Beliefs and Ill-structured Problem-solving in Solo and Paired Contexts, Journal of Educational Technology & Society, 15(1), 15-27.

[2] Barnard, L., Lan, W., Crooks, S., and Paton, V., 2008. The relationship between epistemologieal beliefs and self regulated learning skills on the online course environment. MERLOT Journal of Online Learning and Teaching, 4(3).

[3] Bendixen, L., Schraw, G., and Dunkle, M., 1998. Epistemic beliefs and moral reasoning. The Journal of Psychology, 132(2), 187–200.

[4] Briell, J., Elen, J., Depaepe, F., and Clarebout, G., 2010. The exploration of drawings as a tool to gain entry to students' epistemological beliefs. Electronic Journal of Research in Educational Psychology, 8(2), 655–688.

[5] Brownlee, J., 2004. Teacher education students' epistemological beliefs: Developing a relational model of teaching. Research in Education, 72, 1–17.

[6] Buehl, M. and Alexander, P., 2001. Beliefs about academic knowledge, Educ. Psych. Review, 13, 385-418.

[7] Cajander, Å., Daniels, M., and McDermott, R., 2012. On valuing peers: theories of learning and intercultural competence, Computer Science Education, 22(4), 319-342.

[8] Clarebout, G., Elen, J., Luyten, L., and Bamps, H., 2001. Assessing Epistemological Beliefs: Schommer's Questionnaire Revisited, Educational Research and Evaluation: Int. J. on Theory and Practice, 7(1), 53-77

[9] Daniels, M., Cajander, Å., Clear, T., and Pears, A., 2010. Engineering Education Research in Practice: Evolving Use of Open Ended Group Projects as a Pedagogical Strategy for Developing Skills in Global Collaboration, International Journal of Engineering Education, 26(4), 795-806.

[10] Daniels, M., 2011. Developing and Assessing Professional Competencies: a Pipe Dream? Experiences from an Open-Ended Group Project Learning Environment, Digital Comprehensive Summaries of Uppsala Dissertations from the Faculty of Science and Technology 808, Uppsala, Sweden.

[11] Dweck, C. S. & Leggett, E. L., 1988. A social-cognitive approach to motivation and personality. Psychological Review, 95, 256-273.

[12] Frye, N., Montfort, D., Brown, S., and Adesope, O., 2012. I'm absolutely certain that's probably true: Exploring epistemologies of sophomore engineering students. Proc. Frontiers in Education Conference, Seattle,

[13] Hofer, B., and Pintrich, P., 1997. The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. Review of Educational Research, 67(1), 88-140.

[14] Hofer, B., 2001. Personal epistemology research: Implications for learning and teaching. Educational Psychology Review, 13, 353–382.

[15] Hofer, B. and Pintrich, P., 2002. Personal epistemology: The psychology of beliefs about knowledge and knowing. Mahwah, NJ: Erlbaum.

[16] Hofer, B., 2010. Personal epistemology in Asia: Burgeoning research and future directions. Asia Pacific Education Review.

[17] Jonassen, D., 1997. Instructional design models for well-structured and ill-structured problem-solving learning outcomes. Educational Tech. Research & Dev., 4(1), 65-95.

[18] Kardash, C., and Howell, K. 2000. Effects of epistemological beliefs and topic-specific beliefs on undergraduates' cognitive and strategic processing of dual-positioned text. Journal of Educ. Psychology, 92, 524–535.

[19] King, P., and Kitchener, K., 2002. The reflective judgment model: Twenty years of epistemic cognition. In B. K. Hofer and P. R. Pintrich (Eds.), Personal epistemology: The psychology of beliefs about knowledge and knowing (pp. 37–62). Mahwah, NJ: Lawrence Erlbaum.

[20] Kuhn, D., Cheney, R., and Weinstock, M. 2000. The development of epistemological understanding. Cognitive Development, 15, 309–328.

[21] Laxer, C., Daniels, M., Cajander, Å., and Wollowski, M., 2009. Evolution of an International Collaborative Student Project, Australian Computer Science Communications, 31(5,) 111-118.

[22] McDermott, R, Cajander, Å, Daniels M, Laxer, C., and Pirie, I., 2013. Contemplations on Results from Investigating the Personal Epistemology of Computing Students, in proceedings of ASEE/IEEE Frontiers in Education.

[23] Nielsen, S., 2012. Epistemic beliefs and self-regulated learning in music students, Psych. of Music, 40(3), 324-338.

[24] Perry, W., 1970. Forms of intellectual and ethical development in the college years: A scheme. New York: Holt, Rinehart & Winston.

[25] Peters A.-K. and Pears, A.. 2013. Engagement in Computer Science and IT - What! A Matter of Identity? In Proc. 1st IEEE Learning and Teaching in Computing and Engineering Conference, Macau.

[26] Piaget, J., 1952. The Origins of Intelligence in Children. New York: International University Press.

[27] Qian, G. and Alvermann. D., 2000. Relationship between epistemological beliefs and conceptual change learning. Reading and Writing Quarterly, 16, 59–76.

[28] Ryan, M., 1984. Monitoring text comprehension: Individual differences in epistemological standards. Journal of Educational Psychology, 76, 248-25

[29] Schoenfeld, A., 1983. Beyond the purely cognitive: Belief systems, social cognitions, and metacognitions as driving forces in intellectual performance. Cognitive Sci.,7, 329-363.

[30] Schommer, M., 1990. Effects of beliefs about the nature of knowledge on comprehension. Journal of Educational Psychology, 82, 498–504.

[31] Schommer, M., Crouse, A., and Rhodes, N., 1992. Epistemological beliefs and mathematical text comprehension: Believing it is simple does not make it so. Journal of Educational Psychology, 84(4), 435-443.

[32] Schommer, M., 1998. The influence of age and schooling on epistemological beliefs. The British Journal of Educational Psychology, 68, 551-562.

[33] Schommer-Aikins, M., 2004. Explaining the Epistemological Belief System: Introducing the embedded systemic model and coordinated research approach, Educational Psychologist, 39(1), 19-29.

[34] Tolhurst, D. and Baker, R., 2003. A new approach to a first year undergraduate information systems course. Australian Computer Science Communications, 25(5) 169-177.

[35] Tolhurst, D. 2007: The influence of learning environments on students' epistemological beliefs and learning outcomes, Teaching in Higher Education, 12(2), 219-233.

[36] Voss, J., and Post, T., 1988. On the solving of ill-structured problems. In M. Chi, R. Glaser, and M. J. Farr (Eds.), The nature of expertise (pp. 261-285). NJ, England.