Further studies in self-directed learning in physics at the University of Limerick, Ireland

FURTHER STUDIES IN SELF-DIRECTED LEARNING IN PHYSICS AT THE UNIVERSITY OF LIMERICK, IRELAND

Veronica McCauley and George McClelland

ABSTRACT

This article reports on two SDL studies of undergraduate physics students and postgraduate science students at the University of Limerick, Ireland. Initial studies (McCauley and McClelland, 2001) indicated that the majority of undergraduate physics students are 'average' and 'below' in their readiness to self-direct their learning. Our further investigations lend credence and further support these findings. Results also indicate that small interventions of the nature described here are not successful in evoking large changes, yet they are successful in the exploration of change. The authors propose that an intervention on a much greater scale is warranted, throughout not only the full course, but, in time, across all courses, which all play a part in forming students' models of learning.

A university education should consist of more than students passively receiving information, even though that is what happens in most traditional classroom settings. On one side, there is receiving the information, the easy part; and on the other, there is assimilating the information, fitting it all together, a much more difficult task. Can we assume that once our students reach this stage in their education, that they are ready to synthesise the information given to them? Are university-level students ready to teach themselves? According to Wilcox (1996), universities need to prepare learners to engage in self-directed learning (SDL) processes, not only to improve and enhance their current learning skills, but also to prepare them for lifelong learning beyond the institution's walls.

There is much confusion about what qualifies as SDL; professors and teachers are often confused about what supports and stimulates a SDL environment (Long, 1991b). SDL is a difficult construct to define largely because of the complexity in attempting to encompass a range of elements such as behaviours, perceptions, thought, experience, and communication into a single concept (Grow, 1991a).

According to Knowles (1975) SDL is a process in which "individuals take the initiative, with or without the help from others, in diagnosing their learning needs, formulating learning goals, identifying human and material resources for learning, choosing and implementing appropriate learning strategies, and evaluation of learning outcomes (p. 18)." A detailed literature review (McCauley, 2002) revealed that most SDL definitions seem to be derived in some part from this description. As this definition was also the most descriptive and commonly cited in the literature, the authors chose to use this as a guideline for implementing the process.

AIMS OF RESEARCH

This paper builds upon preliminary research findings (McCauley and McClelland, 2001) that arose from a yearly SDL readiness study and a pilot SDL intervention. These studies were

carried out on undergraduate physics students at the University of Limerick, Ireland. Results indicated that over two-thirds of students from both studies were 'average' and 'below' in readiness to self-direct their learning, and this statistic did not change from the first through the fourth year of their primary undergraduate degree program.

In order to further investigate these findings, a main intervention was proposed, followed by an SDL readiness survey of postgraduate students within the College of Science. The main aim of this paper is to report on the SDL readiness findings from both surveys, and also to explore whether there is any correlation between the undergraduate SDL readiness score and students' self-opinion of their learning style.

Hypotheses formulation and testing was the approach chosen as an investigative technique. This method helped to categorise research questions which arose out of the earlier undergraduate studies, the aim being to find evidence that would support or contradict each statement. Martin (1997) also used this approach and it proved to be a clear and concise method of exploring the key research questions. Results are presented and explored through discussion.

EVALUATION RATIONALE AND TECHNIQUES

According to Robotham (1995), the first step in attempting to develop a learner's ability to self-direct is to assess the current level of self-direction that the individual is able to exhibit. One of the ways in which this quality may be quantified is by using an assessment instrument known as the *Self-Directed Learning Readiness Scale* (*SDLRS*).

The *SDLRS* is a self-report instrument developed by Dr. Lucy Guglielmino while at the University of Georgia. It is a widely used and well-respected instrument (McCune, 1988; Long, 1991a; Guglielmino and Klatt, 1993; Harvey and Harvey, 1995) and according to Guglielmino and Klatt (1993), the instrument has been used with more than 40,000 adults and in over 150 research projects, including more than 50 master's theses and doctoral dissertations.

Although the scale has been largely criticised by Field (1989, 1990), his assertions towards the validity and reliability of the scale were strongly refuted by Guglielmino, Long and McCune (1989). These authors review separately many of Field's (1989) claims, and construct several well-referenced arguments in their defence, further reinforcing the Scale's validity. Guglielmino (Guglielmino, Long and McCune, 1989) states that "there are some problems inherent in the development of any scale" (p. 239) and that constructive criticism is welcome. Although one study questions the soundness of the assessment tool, over seventeen other studies prove its validity, reinforcing and strengthening its ability to assess one's readiness to self-direct learning. The latest in-depth analysis (Delahaye & Choy, 2000) reinforces this view.

Four research techniques were employed in gathering data for these studies: (a) *SDLRS* questionnaires (used in the postgraduate study and also as a method of assessment, pre- and post-main intervention); (b) discussions with and observation of students; (c) a research diary, which was a reflective journal; and (d) structured interviews carried out at the end of the main intervention. Students were asked to volunteer 15-20 minutes to discuss their views regarding the intervention.

Both (b) and (c) were carried out in a very informal manner. Student opinion was accounted for and general behaviour and the flow of the lesson were noted daily in the form of *positive points, negative points* and *suggestions for improvement.*

MAIN INTERVENTION

As a result of preliminary findings (McCauley and McClelland, 2001) and a detailed literature survey, a main intervention was devised, based on the foundation of the pilot intervention. It is important to emphasize here that the main lecture course was taught in a traditional lecture format and that the interventions were offered as a supplementary tutorial.

The Participants

Second and third year undergraduate physics students participated in this intervention. Gender, course type and age statistics from the pilot (autumn semester, 1999) and main (spring semester, 2000) interventions are summarised in Table 1 below.

Table 1. Descriptive statistics for the pilot and main interventions

Intervention	**N**	**Gender**	**Course Type**	**Age**
Pilot	24	71% (M); 29% (F)	75% (AP); 25% (SE)	96%: 17-19
Main	30	60% (M); 40% (F)	73% (AP); 27% (SE)	92.5%: 19-21

The data illustrate that both undergraduate samples were very similar regarding gender and course type. Approximately two-thirds of both samples were male, one-third being female. Also the majority of the students (approximately three-quarters) were following the Applied Physics (AP) degree program, with the remainder studying Science Education (SE). However, there is a distinct age group difference, where the majority of the pilot sample are aged between 17 and 19, and the majority of the main sample are aged between 19 and 21.

Intervention Design

The main intervention evolved from the pilot intervention in terms of structure, subject and pedagogy. The session format changed from eight, two-hour tutor sessions to four tutor sessions and four self-study sessions, carried out alternately, every second week. The aim was to encourage students to take time to self-direct their learning within the support structure of a classroom. The new subject area, "Space and Time" explored quantum mechanics, hydrogenic wave functions and special relativity. Finally, a new model was added to the pedagogical design. The pilot intervention used both the Constructivist model of Cognition (Redish, 1996) and the Staged SDL model (Grow, 1991a, 1996). As interactive learning techniques were successful in improving undergraduate learning (Hake, 1998), aspects of Mazur's (1993) Peer Instruction Model were incorporated as well. An increased selection of computer-based learning software programs was also made available. A description of the pedagogical design is given below.

The Constructivist Model of Cognition. This model was effective in encouraging students to question their learning styles. The tutor acknowledged the fact that students would come to the session with previously formed mental models and beliefs regarding their approach to learning and the content to be learned. Although it is difficult to change an existing mental

model, the tutor encouraged students to think about previous learning experiences. In the opening session, students were invited to discuss their preferred learning styles, and although many admitted that they liked to be given the specific relevant information needed to pass the exam, they also acknowledged that this information was often soon forgotten. The main message from the students was that 'real' learning took place after class, and that studying alone and/or in groups helped commit this information to memory. The tutors' aim was therefore to encourage students to move away from being satisfied with passively receiving information, and to question the content and process used. This process was reinforced using Mazur's Peer Instruction technique described below.

Peer Instruction. Mazur's model of Peer Instruction was incorporated into the intervention by using his technique of teaching by questioning. Students were asked conceptual questions intermittently throughout the sessions. They were then given time to consider the questions and come up with an individual answer. Following this, they were encouraged to discuss and debate their answer with their peers in an attempt to work through and improve their understanding. The tutor explained key concepts throughout the session, to avoid any common misunderstandings. As the sessions progressed, the tutor reduced lecture time and increased student discussion in order to encourage more student-based interaction within the class. This process assumes that the student with the correct answer for the correct reason will usually have a stronger case than a student who has the incorrect answer for the incorrect reason. This model invited lively discussion and student interaction. Many of these conceptual questions were in the form of self–tests composed of a series of multiple choice questions designed to assess the student's understanding of content.

Staged Self-Directed Learning Model. As the sample contained a mixture of different abilities and stages of readiness for SDL, it was difficult to match teaching style to student stages, as suggested by the Staged SDL model. Therefore, we decided to begin the intervention by teaching towards the dependent learner, gradually changing teaching style, from coach to guide, to facilitator and finally consultant. The tutor encouraged the students to work through their tasks by themselves, yet with the knowledge that there was a support structure if needed. The main aim was to attempt to affect and mould learning style, encouraging the students to move from dependency towards autonomy.

Although this intervention also emphasised computer-based learning, we are only going to focus on the SDL aspects of the intervention in this paper.

The following hypotheses, derived from the pilot study are elaborated upon in the discussion:

> Hypothesis 1: There will be no statistically significant difference between levels of SDL readiness before and after exposure to the main intervention.
> Hypothesis 2: There will be no statistically significant difference between the pilot and main intervention SDLRS scores.
> Hypothesis 3: There will be no statistically significant relationship between gender and the levels of SDL readiness of the main sample.
> Hypothesis 4. There will be no statistically significant relationship between age and the levels of SDL readiness of the main sample.

Hypothesis 5. There will be no statistically significant relationship between course of study (Applied Physics and Science Education) and levels of SDL readiness of the main sample.
Hypothesis 6: There will be no statistically significant relationship between final module grade and levels of SDL readiness of the main sample.

POSTGRADUATE STUDY

Having previously carried out a yearly SDL readiness study on undergraduate students (N=53), for comparative purposes, we then decided to investigate the SDL readiness of postgraduate students (N=51). Gender and age were also explored. The sample consisted of research students within the Departments of Life Sciences (LS), Physics, and Chemical and Environmental Science (CES).

The gender statistics indicate that the gender ratio within the LS and CES Departments are very similar: 1/3 male, 2/3 female; and that the Physics Department sample contains the reverse composition: 2/3 male, 1/3 female. The age statistics indicate that 88% of the sample are within the 23-29 age group, with each department containing a mixture of first, second and third year postgraduate students.

For this new study, four more hypotheses were proposed:

Hypothesis A: There will be no significant relationship between levels of SDL readiness and gender within the postgraduate sample.
Hypothesis B: There will be no statistically significant relationship between levels of SDL readiness and the age of the participants within the postgraduate sample.
Hypothesis C: There will be no significant difference between the SDLRS scores of the Life Science, Physics or CES Departments.
Hypothesis D: There will be no statistically significant difference between levels of SDL readiness of undergraduate and postgraduate students within the College of Science at Third Level.

DATA ANALYSIS

Complete data sets were used for comparative analysis between samples (e.g. pilot study sample and main study sample; main study sample and other populations). For comparison within samples, matched pre- and post-test data was used (e.g. *SDLRS* pre-score and *SDLRS* post-score; *SDLRS* scores and age, gender etc.).

In the statistical analysis of our data, we used a number of different tests. The Independent Samples T test was used to compare the pilot study with the main study, *SDLRS* pre- and posttests, *SDLRS* scores and gender, and *SDLRS* scores and course. Pearson's Product Moment Correlations were used to determine if there was a relationship between *SDLRS* scores and age and *SDLRS* scores and grade. The one-sample T test was used to examine the *SDLRS* scores of the study sample in relation to the mean reported for the average adult American population; and

a one-way ANOVA was used to compare *SDLRS* data by departments. Further details are outlined below.

RESULTS AND DISCUSSION

Main Intervention

Hypothesis 1. There was no significant difference between pre- and post-SDLRS scores in the main intervention, indicating that the intervention had no impact on the SDL readiness of these students. We therefore, cannot reject the null hypothesis of equal means.

Although this outcome may have been anticipated, due partly to the fact that this intervention was only a supplementary part of the main instruction of the course (which was predominantly the traditional lecture model), and the short time span, the authors still view it as a successful pedagogical exploration. Results indicate that 68.1% of undergraduate students from the combined interventions (pilot, 65% and main, 70.5%) are 'average' and 'below' in their ability to self-direct their learning, encompassing quite a dominant percentage of the population. Therefore, a larger intervention on a more extensive scale may be warranted, in order to substantially change levels of readiness for SDL.

Table 2. Increase/Decrease in *SDLRS* Scores (Pilot and Main Studies)

SDLRS Scores	N	Increase	Decrease	No Change
Pilot	24	N=12 (50%)	N = 4 (17%)	N = 8 (33%)
Main	30	N=16 (53%)	N = 6 (20%)	N = 8 (27%)

Table 2 indicates that although there was no significant increase in the overall *SDLRS* scores on completion of the interventions, the percentage increase in score far outweighs the percentage decrease in score. Results indicate that approximately one-half of each sample, in both the pilot and main interventions, increased their *SDLRS* score, indicating a positive result. Only one-fifth of each sample decreased in their readiness score and approximately one-third remained the same.

Hypothesis 2. There was no significant difference between the *SDLRS* scores when the pilot and main studies were compared. This was somewhat expected, due to the apparent similarities of both groups, further confirming the findings of previous undergraduate studies (McCauley and McClelland, 2001), which indicated that there was no change in undergraduate SDL readiness from the first year through the fourth year of the sampled degree programs.

The main sample achieved a mean *SDLRS* score of 215.80, sd 22.96. This score not only reflects the scores of previous undergraduate physics studies (mean score $_{(\text{yearly study})}$ = 214.2,sd 21.88 and mean score $_{(\text{pilot study})}$ = 218.25, sd 21.65); it also reflects scores from other undergraduate studies cited in the literature. For example, Beitler (2000) carried out a SDLRS survey on undergraduate business students (juniors and seniors) from the University of North Carolina, Greensboro, US, whose mean SDLRS score was 213.7.

The mean *SDLRS* score for Americans is reported as 214, sd. 25.59. This mean has been used for comparison purposes in various studies (Jones, 1992; Bulik and Romero, 2000 and Choy and Delahaye, 2000). Results indicate that there is no statistically significant difference between our main undergraduate sample and this population.

Hypotheses 3, 4 and 5. Results indicate that there is no significant difference when *SDLRS* scores are categorised by gender or age. We therefore cannot reject the null hypothesis of equal means. Statistics also show that there is no significant difference between *SDLRS* scores when the sample is categorised by course (Applied Physics and Science Education). The Science Education students scored slightly higher overall than the Applied Physics students, yet no significant difference was found.

Similar results were also found in a study carried out by Warner, Christie and Choy (1998) on their Australian sample, where results indicated that there were also no significant differences in the SDL readiness of their sample when categorized by age, gender or course.

Hypothesis 6. Results indicate that there is a significant correlation ($r=.32$, $p=.034$) between the main sample's *SDLRS* score and their end of module grade. We must therefore reject the null hypothesis of equal means. This result indicates that those students who earn a higher-grade average are more likely to have higher levels of readiness for self-direction. A further test was carried out to see if there was any correlation between SDL readiness levels and the sample's current QCA grade (the Irish equivalent of the GPA, an accumulative end of term grade value for all exams carried out to date for each student). The QCA levels indicate an upward trend, in comparison to one's increasing SDL readiness, yet this correlation is not significant.

As part of the interview for the main intervention, the students were shown four different categories of learner and were asked to indicate and explain which category best described them. The categories were classified according to four types of learner which are described in Grow's (1991b) Staged SDL Model: *Dependent, Interested, Involved* and *Self-directed* learners.

Results indicate that none of the sample who carried out the interview sessions (undergraduates from the main study) feel that they are 'Dependent' learners. This statistic seems to contradict the sample's readiness to participate in SDL activities, as 27.5% of this sample scored 'below average' and 'low' in their SDLR. Of the sample 56% did claim to have been dependent learners in the past, yet believed that this role had diminished on entering post-secondary school education.

Three-quarters of the sample believe that they are 'Interested' and 'Involved' learners. This statistic may be compared with the fact that 43% of the sample scored 'average' in their ability to self-direct their learning. Approximately one-fifth of the sample feel that they are 'self-directed' in their learning, which may be compared with 29.5% of the sample who scored 'above average' and 'high' in their ability to self-direct their learning.

Overall, there seems to be loose correlation between self-opinions and actual results, although the participants seem to be of the opinion that they are more self-directed than the *SDLRS* indicates.

Postgraduate Study

Hypotheses A and B. Results show that there is no significant difference between male and female scores within and between departments in relation to their *SDLRS* score, although males (mean score = 227.14, sd 25.45) score slightly higher than females (mean score = 219.82, sd 25.56). Our findings also show that there is no significant correlation between the age of the postgraduate population and their *SDLRS* score. Therefore we cannot reject the null hypothesis of equal means for either of the two hypotheses, reflecting similar findings as those reported in the undergraduate studies.

Hypothesis C. The mean *SDLRS* scores for each department are very close: Mean Score $_{(LS)}$ = 227.80, Mean Score $_{(Physics)}$ = 231.44 and Mean Score $_{(CES)}$ = 222.83. Results indicate that there are no significant differences among the departments' *SDLRS* scores. Further analysis shows that the majority of students from each department (LS: 60%, Physics: 55% and CES: 52%) scored 'above average' and 'high' in their ability to self-direct their learning, indicating that the majority of this group are ready to succeed in a SDL environment.

Hypothesis D. The distribution curve of the postgraduate sample (mean score = 227.66) is similar to that of the undergraduate main sample (mean score = 215.80), yet the mean *SDLRS* score has shifted to the right, indicating that the postgraduate sample scored significantly higher than the undergraduate distribution. The results indicate that 45% of the sample is 'average' and 'low' in their SDL readiness, leaving the majority (55%) of the students to be 'above average' and 'high' in their ability to self-direct their learning. As there is a significant difference (t=-2.36, p=.02) between the postgraduate and undergraduate samples' ability to self-direct their learning, we therefore cannot accept the null hypothesis of equal means.

This may be explained by the fact that this unique group of students have had a much more rigorous experience of SDL from the outset. Students have been subjected to Stage 4 SDL teaching methods (as indicated in Grow's Staged SDL model). According to Grow (1996), the role of a Stage 4 teacher is more of a consultant than a mentor. He compares their role with that of many graduate professors/supervisors, which he describes as follows: "They set a challenge, then leave the learner largely alone to carry it out, intervening only when asked to help…and then not help meet the challenge, but help empower the learner to meet the challenge. They supervise the learner in a project or thesis, stay far enough away for the student to progress alone, but remain available for consultations."

Grow's description above clearly depicts the role of a supervisor over postgraduate research. For this reason, it is more likely for a postgraduate student to take on a more self-directed role, as this is the environment in which they are required to work. Consequently, it is not surprising that the mean score of the postgraduate sample (227.66) is practically the same as that of the meta-analytic investigation of 29 studies (n=4,596) cited by Guglielmino (2002) and McCune, Guglielmino and Garcia (1990). The latter study was carried out on mostly college students,

grad students and professionals in the U.S., where the overall mean *SDLRS* score was reported to be 227.7.

CONCLUSIONS

SDL Readiness of Undergraduate Students

Our research shows that there was no significant difference in SDL readiness when data was categorized by gender, age and department, as is reflected in the general literature. Our studies indicate that the majority of undergraduate physics students scored 'average' and 'below' on the *SDLRS*, also reflecting similar studies cited in the literature on undergraduate/college students, lending credence to these statistics.

Results indicate that although there was no significant increase in the samples of their SDL readiness on completion of the interventions; approximately 50% of both the pilot and main samples increased their score. The results also show that students with higher grade averages are more likely to have higher levels of self-direction, which may be an interesting avenue to explore in future studies.

Self-Placement in Grow's Typology as Compared to SDLRS Scores

Overall, there seems to be some correlation between the main sample's SDLRS scores and their self-opinions of their learning approach based on Grow's typology. However, results indicate those with lower levels of readiness were of the opinion that they are more self-directed than the SDLRS indicates. No students were willing to classify themselves as dependent learners.

SDL Readiness of Postgraduate Students

Results indicate that there is no significant correlation between gender, course type or age, and SDL readiness score among postgraduate students, reinforcing similar findings in the undergraduate sample, and samples cited in the literature. The majority of postgraduate students are 'above average' and 'high' in their SDL readiness, implying that they are at a stage where most of the sample is ready to self-direct their learning. Consequently, the postgraduate sample scored significantly higher than the undergraduate sample in terms of their SDL readiness, which is not surprising due to the nature of their work, maturation and changes in expectations and methods of instruction.

In Summary

The research reported in this paper indicates that the undergraduate physics students studied here are not, in general, well prepared to self-direct their own learning. This result leads us to further question our teaching techniques. Currently, the majority of lecturers still use the traditional format of teaching and assessing learning: giving information to a passive audience, assuming that they will take the time after class to assimilate and make sense of it all. What happens if our students do not take the time to synthesise this information? What happens if they find it an easier solution to rote learn the relevant information, in an attempt to merely succeed within the

set exam format, and focus on short-term memory? Should we be satisfied knowing that the majority of our students may resort to these measures, as they have not received the training to do otherwise?

Interventions are required in order to teach students how to self-learn and progress from rote learning to understanding, not only throughout their undergraduate education but also beyond. Results from our postgraduate sample indicate that these students are ready to participate in self-learning activities. Methods of independent learning may be a factor in encouraging students to progress further in their education, with or without the support of others.

Results indicate that interventions of the type described here were not as effective as initially anticipated in raising levels of SDLR by the metrics used. The literature indicates that SDL is extremely desirable at this level, but there is very little supporting literature on how it can be achieved, and the extent of intervention required. The authors suggest that previous learning experiences (in secondary level education) may be responsible for establishing dependency among students. Traditionally delivered courses at university in the main reinforce habits of passive and dependent learning. In order to break these habits of dependence, an extensive interactive intervention is warranted. Although small interventions are welcomed to explore possibilities; larger-scale interventions are necessary, not alone in one module, but across all modules, in order to help mould and support one's learning model. This would require a deliberate, planned, coordinated and monitored effort on the part of a Department and Course Team, with consequent implications for faculty time and resources. Further research is required in this area before definite conclusions can be drawn.

REFERENCES

Beitler, M. A. (2000). Self-directed learning readiness at General Motors Japan. Retrieved February, 2002 from http://icdl.uncg.edu/ft/060600-01.html.

Bulik, R.J, Romero, C.M. (2000). The elusive concept of self-directed learning. In H.B. Long & Associates (Eds.), *Self-directed learning and the information age, (pp. 1-18).* SDL e-Publication. Interactive Publishing by New Media Design Centre, Motorola University, Copyright © 2001 Motorola University Press, USA.

Choy, S., & Delahaye, B. (2001). Do youth with high scores in the learning preference assessment instrument have a deep approach to learning and an andragogical orientation to study? In H.B. Long & Associates (Eds.) *Self-directed learning and the information age*. SDL e-Publication. Interactive Publishing by New Media Design Centre, Motorola University, Copyright © 2001 Motorola University Press, USA.

Delahaye , B., & Choy, S. (2000). *The Learning Preference Assessment (Self-Directed Learning Readiness Scale*). In Maltby, J., Lewis, C. A., & Hill, A. (2000). *Commissioned reviews of 250 psychological tests.* Edwin Mellen Press, Wales, U.K.

Field, L. (1989). An investigation into the structure, validity, and reliability of Guglielmino's self-directed learning readiness scale, *Adult Education Quarterly*, *39* (3) 125-139.

Field, L. (1990). Guglielmino's self-directed learning readiness scale: should it continue to be used? *Adult Education Quarterly*, *41*(2), 100-103.

Grow, G. O. (1991a). Teaching learners to be self-directed, *Adult Education Quarterly, 41(3),* 125-149.

Grow, G. (1991b). The staged self-directed learning model. In H. B. Long & Associates (Eds) *Self-directed learning: Consensus and conflict* (Norman, OK: Oklahoma Research Center for Continuing Professional and Higher Education of the University of Oklahoma).

Grow, G. (1996). Teaching learners to be self-directed. Retrieved November, 2000 from http://www.longleaf.net/ggrow.

Guglielmino, L.M. Long, H.B and McCune, S.K. (1989). Reactions to Field's investigation into the SDLRS. *Adult Education Quarterly*, *39* (4), 235-245.

Guglielmino, P. J., & Klatt, L. A. (1993). Entrepreneurs as self-directed learners. Retrieved March, 2000 from http://www.sbaer.uca.edu/Research/1993/ICSB/93ics206.htm.

Hake, R. R. (1998). Interactive-engagement vs traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *Am J. Phys*. *66*, 64- 74.

Harvey, B., & Harvey, C. M. (1995). Learning styles and self-directed learning in Indonesian distance education students. Retrieved March, 2000 from http://www.educ.uvic.ca/connections/Conn95/12-harvey.html.

Jones, J.E. (1992). Validation study of the *Self-Directed Learning Readiness Scale* with university and community art students. In H.B. Long & Associates (Eds.), *Self-Directed Learning: Application and Research (pp. 131-146).* Norman, OK: Oklahoma Research Center for Continuing Professional and Higher Education of the University of Oklahoma.

Knowles, M.S. 1975. *Self-directed learning: A guide for learners and teachers.* Association Press: New York.

Long, H. B. (1991a). Challenges in the study and practice of self-directed learning. In H.B. Long & Associates (Eds.), *Self-directed learning: Consensus and conflict* (pp. 11-28). Norman, OK: Oklahoma Research Center for Continuing Professional and Higher Education of the University of Oklahoma.

Long, H. B. (1991b). Self-directed learning: Consensus and conflict. In Long, H.B. & Associates (Eds.), *Self-directed learning: Consensus and conflict* (pp. 1-10). Norman, OK: Oklahoma Research Center for Continuing Professional and Higher Education of the University of Oklahoma.

Martin, R. (1997). Constructivism and transformative learning theories. Retrieved November, 2000 from http://www.inspiredinside.com/learning/Construct/1-warmup.htm.

Mazur, E. (1993). Understanding or memorization: Are we teaching the right thing? In Wilson, J. (Ed) *The conference on the introductory physics course*. (New York, Rensselear Polytechnic Institute).

McCauley, V. & McClelland, G. (2001). Development of information technology based self-directed learning in physics at the University of Limerick. In Long, H.B. and Associates (Eds.), *Twenty-first century advances in self-directed learning* (pp. 101-126). Florida: Motorola University Press.

Mc Cauley, V. (2002). The development of information technology-based self-directed learning in physics. Doctoral Thesis. University of Limerick: Limerick, Ireland.

Mc Cune, S. K. (1988). A statistical critique of Field's investigation. *Adult Education Quarterly, 39,* 243-246.

Mc Cune, S.K.; Guglielmino, L.M., & Garcia, G. (1990). Adult self-direction in learning: A preliminary meta-analytic readiness scale. In H.B. Long & Associates (Eds.), *Advances in self-directed learning research* (pp. 145-156). Norman, Oklahoma: Oklahoma Research Center for Continuing Professional and Higher Education. Redish, E. F. (1996). New

models of learning and teaching. Retrieved June, 1999 from http://www.physics.umd.edu/rgroups/ripe/papers/jena/jena.html.

Robotham, D. (1995). The ultimate learning style. Retrieved June, 1999 from http://www.wlv.ac.uk/~bu1821/files/self-dir.htm.

Warner, D., Christie, G., & Choy, S. (1998). Flexible delivery, the Internet and other learning technologies: Student factors. Retrieved September, 2001 from http://www.cegsa.sa.edu.au/acec98/papers/p_christie.html.

Wilcox, S. (1996). Fostering self-directed learning in the university setting, *Studies in Higher Education, 21(2),* 165-176.

Veronica McCauley is a lecturer in science education at the National University of Ireland, Galway. Her primary degree was in science education, which instigated doctoral research in Self-Directed and Computer-Based Learning. Following this, she has carried out postdoctoral research in initial teacher education and interactive learning environments at the University of Limerick (Ireland) and Harvard University (Cambridge, USA). (veronica.mccauley@nuigalway.ie)

George McClelland is a Senior Lecturer in Physics and Head of Department, Course Director for the B.Sc. (Ed) Physical Science degree, and Director of the Lucent Science Teacher Initiative in the University of Limerick. Current research interests include physics education and initial science teacher education. (george.mcclelland@ul.ie)