Recommendations for Electronic Laboratory Notebooks in Undergraduate Engineering Faculty:

A student-led case study

N J Cooke[1]
School of Engineering Teaching and Learning Centre
University of Birmingham
Birmingham, United Kingdom
E-mail: n.j.cooke@bham.ac.uk

PT Robbins, JM Lodge, I Shannon, KIM Hawwash
College of Engineering and Physical Sciences
University of Birmingham
Birmingham, United Kingdom

JM Lodge
College of Life and Environmental Sciences
University of Birmingham
Birmingham, United Kingdom

ABSTRACT

Industry and academic research labs increasingly use Electronic Laboratory Notebooks (ELN). In engineering education, the ELN affords new laboratory technologies and pedagogies requiring embedding rich data and supporting virtual labs. We present a student-led design of a prototype ELN based on Microsoft OneNote software for our undergraduate engineering programmes. The solution addresses the requirements for lab redesign aspirations around new laboratory pedagogies requiring entirely digital workflows. To enhance the solution's ecological validity, students themselves developed it while undertaking their existing undergraduate labs. The result is an ELN based on the digital notetaking software Microsoft OneNote. We make available a requirements and design tool that includes a set of 21 use cases, 102 requirements, and 32 failure modes. Staff and student feedback is reported. The work will assist engineering and science faculty looking to introduce an ELN solution into their curricula.

Conference Key Areas: Open and Online Engineering Education, Curriculum Development, Skills and Engineering Education.

Keywords: Electronic Laboratory Notebook, Microsoft OneNote, Educational Technologies, User acceptance.

---

[1] NJ Cooke
n.j.cooke@bham.ac.uk

INTRODUCTION

Digital notetaking is becoming the norm in personal and professional endeavours due to the maturity and ubiquity of software and hardware devices which provide capabilities beyond paper. In the laboratory or workshop in undergraduate engineering education, paper notetaking and capture is common and often preferred; sketching is perceived as easier on paper [1], there are several competing technology options for digital notebooks with no obvious winner [2], and faculty staff can be late and/or cautious adopters of new technology [3].

The Electronic Laboratory Notebook is commonly used in industrial research laboratories where there is a strong requirement for capturing Intellectual Property (IP) [4]. ELN use is less common in engineering education; the IP requirement manifests itself chiefly for assisting assessment logistics and plagiarism detection, the latter which is primarily deterred by designing it out of assessment [5]; retaining paper notes may in fact reduce student motivation to plagiarise through increased effort compared to “copy and paste”.

Several recent studies have evaluated the perceived benefits of ELN using contemporary hardware devices such as laptops and tablet devices with stylus. A non-exhaustive list of ELN benefits from these studies includes graph plotting; rich media use; connecting to equipment for control and data capture; embedding and analysing raw data; automatically saving progress; revision capabilities, standardisation and neatness via templates, multiple device access; collaboration and sharing content remotely. For staff, ELN benefits include remote assessment; annotation capabilities; auto grading potential; aggregation and searching of students’ work [6] [7].

In this study, we are interested in what student-driven recommendations could be made to engineering faculty for adopting an ELN solution. To answer this, undergraduate students with at least 2 years’ higher education from faculties of biosciences, civil, mechanical, computer, electrical and chemical engineering were tasked to develop an ELN solution based on their experiences. In addition to prioritising feature expectations and evaluating user acceptance, we asked them to consider broader lifecycle issues including training, operations and maintenance. The work was undertaken in the context of developing a contemporary learning space – the Collaborative Teaching Laboratory at the University of Birmingham [8]. We describe the resulting prototype ELN based on Microsoft OneNote software from design and requirements perspectives. We report feedback received from several evaluations, and we conclude with lessons learned and a requirements tool for faculty looking to develop their own ELN.

1 REVIEW OF ELECTRONIC LAB NOTEBOOKS

ELNs have existed since desktop computers first appeared in research labs. The 1980s locally networked computers lead to a focus on developing collaboration possibilities around shared file stores. The hardware and software advances of the 1990’s stimulated increased focus on function and usability such as inputting, capturing and analysing data. The advent of the internet afforded information mining and meta-data to maximise IP value [9].

Their use in Engineering undergraduate education has a smaller pedigree. Several recent case studies have been reported that give a mixed picture in terms of the benefits of an ELN over paper. Notably in [1], students did not generally make use of rich media such as images and video to enhance reporting. In [6], staff and student ratings of a commerical ELN “Lab Archives” were positive in terms of its function, however training requirements were highlighted as a key barrier to uptake. Many ELN benefits come only after the initial note input, such as searching and revising past entries, which may not always be required. The structure to input that the ELN can impose could also be at the expense of the flexibility that a blank sheet of paper affords [10]; structured templates in ELN, e.g. defined sections and autofilling tables with correct formulae, can prevent students from “being able to produce their own structure and engage in organise their work” [2]. These previous works motivated us to develop the requirements and design tool reported here to evaluate potential ELN solutions.

There are numerous commercial ELN softwares used in research activity across sciences and engineering. These include SciNote, LabFolder, LabArchives, LabWare, Docollab and LabGuru. In contrast to these softwares, general digitial notetaking solutions such as Microsoft OneNote and Evernote can be adapted to serve as an ELN, particularly when teaching activity takes precedent over project-oriented research activity. These general softwares benefit from no imposed lab structure, cross-platform support, and mass-market maturity; e.g. in [11], OneNote – the software used in this study – enabled an ELN to be accessible on a newly released smart watch to free up users hands during practical.

The ELN is a part of the bigger challenge to evolve engineering educcation laboratory pedagogy in the digital age. In [12], the proposed Electronic Lab Assessments with Tutoring Enhanced Delivery (ELATED) laboratory pedagogy is typical of modern lab redesign efforts, highlighting the requirement for lab assessment combined with reflective portfolios, demonstrations and reports. All of these outputs contribute to an entirely digital lab profle for every student.

2 REQUIREMENTS AND DESIGN

2.1 Lifecycle and project scope

The ELN solution (*Fig. 1*) was developed by undergraduate student interns over summer 2016. The project consisted of students developing a solution based on Microsoft OneNote for use on tablet devices (Microsoft Surface Pro 4s and Ipad Air 2) and mobile phones and desktop computers while they undertook existing labs from several STEM disciplines. Use cases and detailed requirements were captured. Evaluation activities included failure modes analysis, and user acceptance trials. Students were tasked to consider operational aspects of the solution. These included fault handling and maintenance procedures, and student/staff training requirements including user manuals and training videos.

2.2 Requirements and Use Case

Initial observations and run-throughs of labs resulted in the identification of 21 key use cases with the associated actors, goals, pre-conditions, success scenarios, extensions and post conditions. The use cases are: adding students to notebooks, creating ELN, printing ELN, marking ELN, erasing input, using templates, excusing attendance, creating search queries, viewing content libraries, graphing, adding feedback, viewing feedback, login, logout, adding assignment, view individual student ELN, collaborate, seek assistance, change page layout and view revision history. From these use cases, 102 requirements are identified which are grouped into several sections: User interfaces, functional, performance, hardware, security, software quality. Furthermore, 37 failure modes are identified for consideration during design testing. These are available in the requirements and design tool described in section 4.

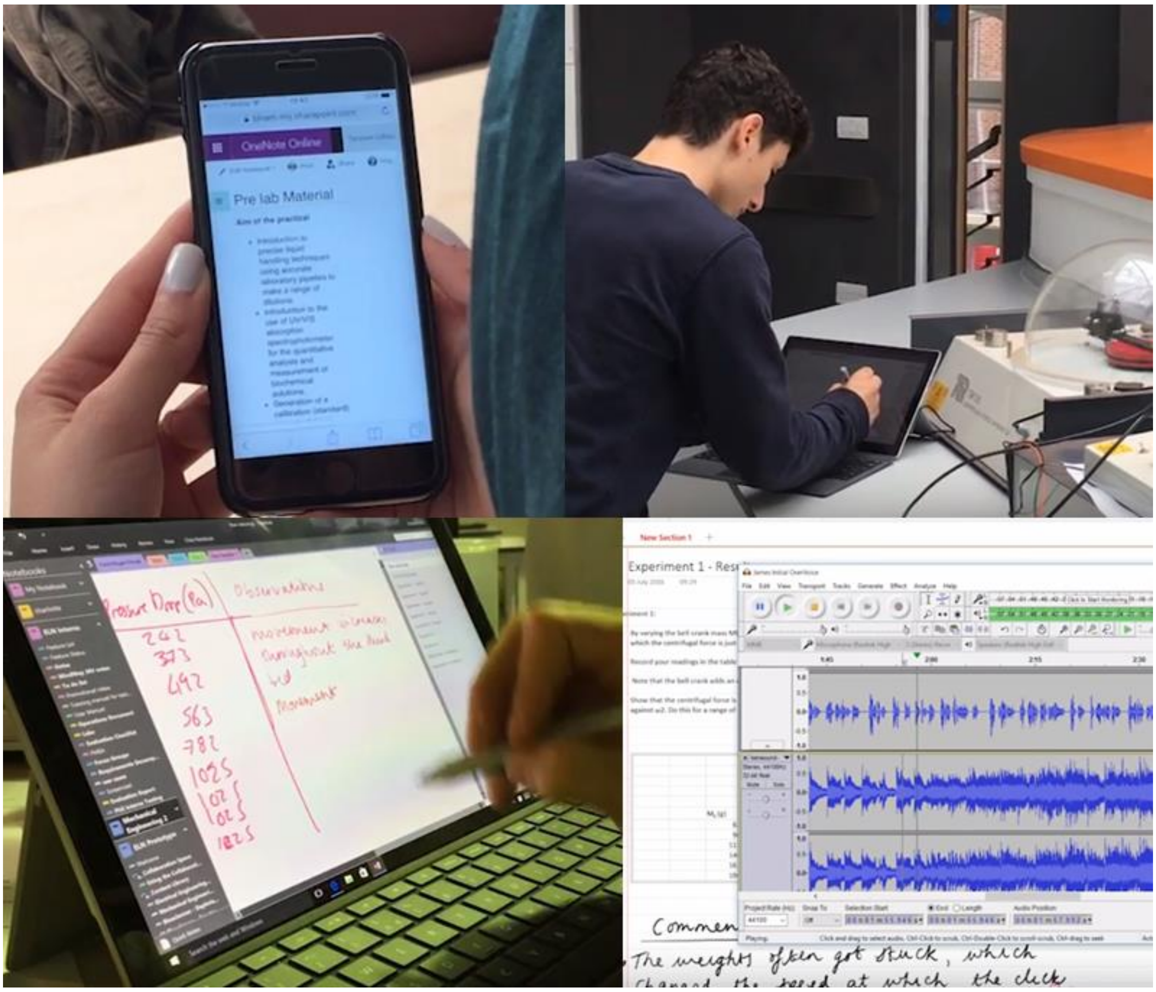

Fig. 1. ELN Solution – smartphone access to pre-lab materials (1a top left), data logging capabilities (1b top right), sylus input (1c bottom left), data embedding (1d bottom right)

2.3 Design

Fig. 2 outlines the ELN solution architecture, illustrating how users interact with the three primary components – notetaking software, cloud service and the Virtual Learning Environment (VLE). The first component is the notetaking software - Microsoft OneNote 2016 with class notebook add-in. It conforms to a traditional notebook with sections comprising of ordered pages. It supports stylus and keyboard input, and the embedding of other objects in-line with text such as rich media, data attachments and spreadsheets. The second component is the cloud service - Microsoft Class Notebook / OneDrive cloud. Rather than students downloading personal copies of the notebook, they all work on this same cloud-based notebook. Student's individual sections are not visible to one-another, and the cloud solution enhances data security and eases assessment logistics; making updating and distributing content efficiently. Important functionality is provided by the Class Notebook plugin. It gives students access to a shared content library and collaborative sections, along with their own individual working spaces which the teacher can access and grade. The third component is the VLE – in our case, Canvas by Instructure. Faculty teaching staff have the choice of marking the notebook through the VLE, or through Class Notebook plugin in line with local policy.

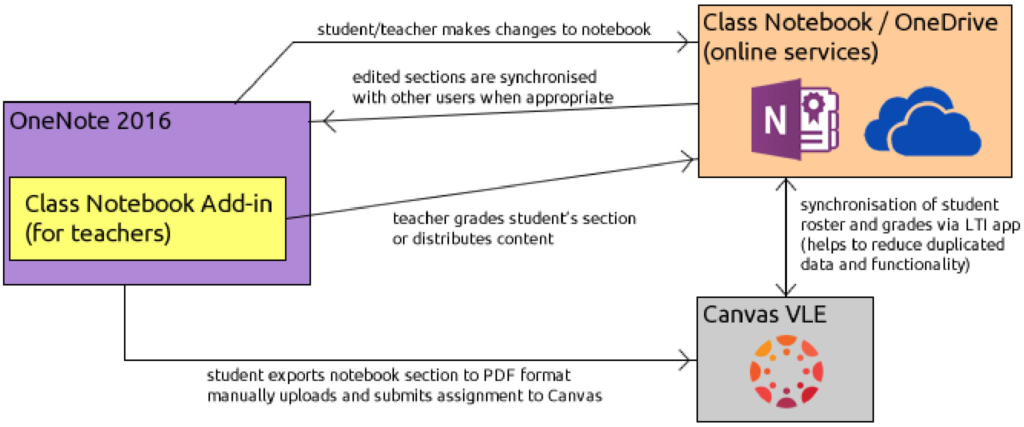

Fig. 2. The ELN architecture based on Microsoft OneNote**.**

3 EVALUATION

3.1 Outcomes from observational analysis

The student developers conducted several laboratory sessions in diverse subjects including chemical engineering, mechanical engineering, electrical engineering, biosciences and chemistry. They made detailed observations during the sessions to ascertain the benefits of the ELN over existing laboratories. A representative sample of the key benefits they observed are summarised in *Table 1*.

Table 1. Key benefits of ELN identified by developer from prototype lab sessions

Existing paper-based Laboratory - observation	**Enhancements provided by the ELN**
Demand by students on staff for orientation and support e.g. locating materials.	*Prelab material in the ELN assists in orientation e.g. VR walkthroughs. The ELN should not to reduce interaction opportunities but instead orient them towards intended learning outcomes.*
Many exercises require students to submit diagrams.	*The stylus functionality appears neater than paper for free-hand drawing but more cumbersome.*
Evidence of lab progress relies on the quality of final answers.	*Students can demonstrate progress by inserting media into the ELN but few do unprompted.*
Lab sheets have a linear structure – students step through them methodically during labs.	*The ELN include pre- and post-lab activity work and also allows students to hyperlink to different sections allowing a non-linear workflow.*
Tables typically require hand written input and the use of calculators to compute values.	*Data is input directly into spreadsheets and tables, allowing for automatic calculation of derived quantities and graphing.*
Students bring a USB stick to the lab to save the data recordings.	*Data logging software can sit on the same platform as the ELN*

3.2 User Acceptance

We conducted several user acceptance studies. 30 undergraduate engineering students were given a demonstration of the solution outside of the laboratory. They were asked to rate it overall on a five-point Likert scale. The average rating was *4.8* with a standard deviation of *0.4*. All but 2 students from this cohort said that they would recommend the solution. 9 academics who teach undergraduate modules were individually presented with the ELN software solution at the laboratory bench. They were asked to run through a mechanical engineering experiment on centrifugal forces shown in Fig. 1b. They each scored the ELN on a five-point Likert scale in comparison to paper notebooks against 14 key features adapted from existing evaluations in the literature [1]. Correspondingly, 19 3rd year undergraduate engineering students undertaking a third-year laboratory in Virtual Reality were asked to use the same ELN software and complete the same questionnaire. Overall students rated the solution higher than the academics (*Fig. 3*). Both student and academics rated most functions higher than paper, assumed to be a mean score above 2.5. The weakest comparisons with paper were “1. making handwritten notes”, “2. adding formulae”, and “3. sketching diagrams”. This is despite the use of tablet devices equipped with a stylus, and it suggests that core notebook functions of data entry are still preferable in paper despite recent hardware advances. There is a smaller variance in the student scores compared to academics which may be attributed to the greater number of participants.

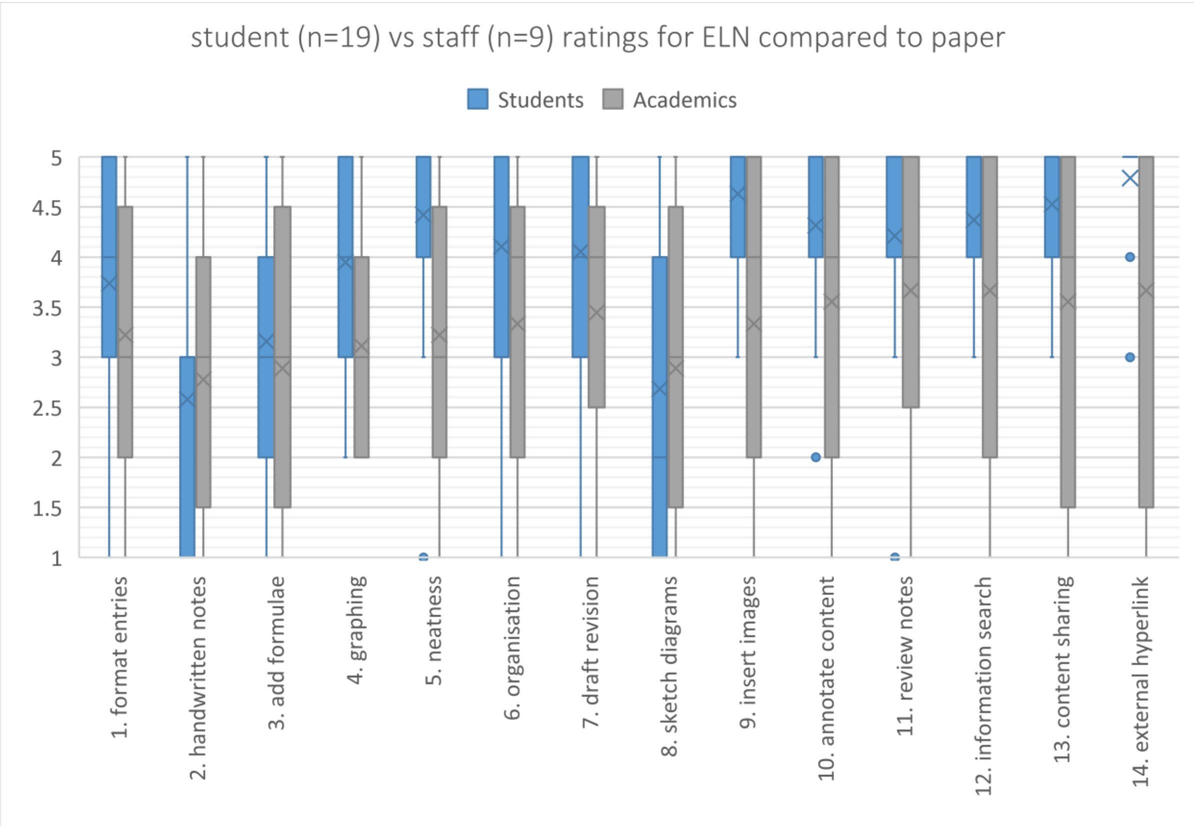

Fig. 3. Student and Academic ratings of ELN Feature benefits over paper based laboratory.

Academics were further queried on assessment of notebook, and all respondents considered grading the work via the VLE more important than grading the work within the ELN solution to ensure common practice with other non-laboratory assessments. Positive comments from academics included “Set out of information is good, input of data occasionally fiddly”; “It prepares students for the next academic and professional levels”; “Minimises paper use, allows rich content, interaction and data sharing.”; “Makes it easier to prepare the lab work and facilitates group working.”; “Easy to mark”;

"easy to keep protocols/instructions updates". Negative comments from academics included "The benefit should be on the lab itself and its redesign to take advantage of the ELN.". Positive comments from students includes "Easier to organise, share and implement pictures, videos and record audio" and "It is neater. Straight lines are easier to draw, easier to copy image". Negative comments from students included "Computer could crash midway through notetaking". Finally, 6 students undertaken a mechanical engineering laboratory in fluid dynamics were given the ELN to make notes instead of a paper, which was used by the other 12 students in the cohort. The key difference between the groups was that a key component of the experiment – graphing pipe pressures and flows – was automated by spreadsheet. This reduced the time taken by students to produce results and lead to more time available for results analysis.

4 ELN DESIGN AND EVALUATION TOOL

We have made a tool to assist engineering faculty in evaluating their own ELN solutions. It consists of a set of 21 use cases for ELN, 102 associated requirements, 32 failure modes for designing against, and the architecture and user manual for our OneNote based solution. It is available on request to faculty from the following URL: http://www.tinyurl.com/SEFI-ELN-REQUEST. A student-produced video of the solution is also available at this URL.

5 SUMMARY

An ELN for Engineering faculty is presented and evaluated. It encourages rich media use and makes data processing and manipulation efficient through e.g. embedded spreadsheets. Collaboration capabilities are a key strength which allow sharing of data and notes. Software for many types of lab equipment can be installed on the hardware platform which runs the notetaking software to facilitate data embedding. The ELN simplifies the submission of lab work and eases marking burdens. Against this, like all cloud-dependent solutions, collaboration functions require stable network connections, and there is an outlay required in terms of equipment, maintenance and training. Despite these shortfalls, it reduces the quantity of paper required reducing carbon footprints, and promotes digital literacy.

With the current advances in mass-market tablet devices with stylus and cloud-based mass-market notetaking software that operates on multiple hardware platforms, ubiquitous ELN in undergraduate engineering education is now realisable. Future work includes enhancing the laboratory sessions that currently use the ELN to take advantage of the graphing, data embedding and collaborative features that the technology affords.

6 ACKNOWLEDGMENTS

The authors would like to thank students Moushami Verma, Joseph Crolla, Jonathan Keslake, Tanzeel Gillani, Charlotte Birch, Jeremy Clarke and Project Manager Chloe Hancox for their contributions to this work which was undertaken with an Educational Enhancement Fund from the Centre of Learning and Academic Development at the University of Birmingham.

REFERENCES

[1] M. Cardenas, "Electronic Laboratory Notebooks versus Paper Laboratory Notebooks: A Comparison of Undergraduate Experimental Engineering

Laboratory Submissions.," in *Proceedings of the 2014 American Society for Engineering Education Zone IV Conference*, 2014.

[2] J. Johnston, S. Kant, V. Gysbers, D. Hancock and G. Denyer, "Using an ePortfolio system as an electronic laboratory notebook in undergraduate biochemistry and molecular biology practical classes.," *Biochemistry and Molecular Biology Education,* vol. 42, no. 1, pp. 50-57, 2014.

[3] D. I. and P. U., "A pocket guide to electronic laboratory notebooks in the academic life sciences," F1000Research 5:2, 2016.

[4] D. Butler, "Electronic notebooks: A new leaf ," *Nature,* no. 436.7047, pp. 20-21, 2005.

[5] M. Jones and L. Sheriden, "Back translation: an emerging sophisticated cyber strategy to subvert advances in 'digital age'plagiarism detection and prevention," *ssessment & Evaluation in Higher Education,* vol. 40, no. 5, pp. 712-724, 2015.

[6] T. J. Puccinelli, "Bringing technology to the First Year Design Experience through the use of Electronic Design Notebooks," *American Society for Engineering Education,* p. 26:1, 2015.

[7] S. Guerrero, G. Dujardin, A. Cabrera-Andrade, C. Paz-y-Miño, A. Indacochea, M. Inglés-Ferrándiz, H. Nadimpalli, N. Collu, Y. Dublanche, I. De Mingo and D. Camargo, "Analysis and Implementation of an Electronic Laboratory Notebook in a Biomedical Research Institute.," *PloS one,* vol. 11, no. 8, 2016.

[8] N. Cooke, P. Robbins, G. MJ, Q. SF, J. Binner and G. JR, "Remolding the UK STEM Graduate for 2020: The Collaborative Teaching," in *European Society for Engineering Education SEFI 2016*, Tampere, 2016.

[9] C. L. Bird, C. Willoughby and J. G. Frey, "Laboratory notebooks in the digital era: the role of ELNs in record keeping for chemistry and other sciences.," *Chemical Society Reviews,* vol. 42, no. 20, pp. 8157-8175, 2013.

[10] G. J. Fakas, A. V. Nguyen and D. Gillet, "The electronic laboratory journal: a collaborative and cooperative learning environment for web-based experimentation.," *Computer Supported Cooperative Work (CSCW),* vol. 14, no. 3, pp. 189-216, 2005.

[11] G. Santiago, "Analysis and Implementation of an Electronic Laboratory Notebook in a Biomedical Research Institute," *PloS one ,* vol. 11, no. 8, 2016.

[12] R. DeMara, "Strengthening STEM Laboratory Assessment Using Student-Narrative Portfolios Interwoven with Online Evaluation.," in *American Society for Engineering Education Southeast Section Conference*, Tuscaloosa, 2016.